Smart e-Health System for Real-time Tracking and Monitoring of Patients, Staff and Assets for Healthcare Decision Support in Saudi Arabia

Awad Ali Alyami

Ph.D.

2018

Abstract

Healthcare in Saudi Arabia has been lagging behind the developed countries of the world, due to the insufficient number of healthcare practitioners and the lack of applications of tracking and monitoring technology. These shortages have contributed to problems such as patient misidentification, long patient waiting times, and the inability to locate medical equipment efficiently. The country's Vision 2030 plan outlines ways to solve the deficient workforce problem by promoting more local health-related educational outlets, and by funding this expanding sector. Consequently, Saudi Arabia needs to adapt to the demanding nature of modern healthcare, which presents major problems that this research aims to help solve. The literature has shown that Information Technology systems have begun to be implemented in some hospitals across Saudi Arabia, but even in those hospitals these technologies are being under-utilised.

The intention of this thesis is to provide an appropriate choice for a real-time tracking and monitoring technology in healthcare, in the form of an integrated RFID/ZigBee system. This thesis develops a holistic framework for healthcare institutions, to be followed for customised solutions in improving staff efficiency and productivity, and for better patient care, while minimising long-term costs. This holistic framework incorporates contextual elements from both the Information System Strategy Triangle (ISST) and the Human, Organisation and Technology-fit factors (HOT-fit) frameworks, in a way that ensures the new framework addresses technology, organisational, human and business factors. The holistic model is refined through Communities of Practice (CoPs), one of which was developed and utilised for the research purposes of this thesis, and assisted in the creation of a questionnaire for assessing the requirements and challenges of the KSA healthcare system. This questionnaire was based on 220 usable responses. It also helped to refine the framework for its final version, which included all identified factors relevant to the decision a healthcare institution faces in choosing a health information technology system.

Various cases were analysed to improve the hospitals workflow, using the proposed technology and including processes such as relocating staff and medical assets. This led to the need for visualisation and knowledge management, to support real-time data analysis for business intelligence decision making. The end goal of this analysis is to provide interactive platforms to healthcare staff for use in improving efficiency and productivity. The outcomes of these improvements will be to ensure better patient care, lower patient waiting time, reduced healthcare costs, and to allow more time for staff to provide improved patient-centric care in the Saudi healthcare sector.

Keywords: e-Health, Health Information Technology, Tracking and Monitoring System, Kingdom of Saudi Arabia, Holistic Framework, Communities of Practice, Knowledge Management, Visualisation, KFMC

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List of Abbreviations

CBA	Cost-Benefit Analysis
CoPs	Communities of Practice
EHR	Electronic Health Record
EMR	Electronic Medical Record
GPS	Global Positioning System
HIS	Hospital Information Systems
HIT	Health Information Technology
HOT-fit	Human- Organisation-Technology model
ICT	Information and Communication Technology
ICU	Intensive Care Unit
IS Triangle	Information System Strategy Triangle
IT	Information Technology
KA	Knowledge Acquisition
KBS	Knowledge Based System
KMS	Knowledge Management System
KM	Knowledge Management
KPI	Key Performance Indicator
KSA	Kingdom of Saudi Arabia
LAN	Local Area Network
MAC	Medium Access Control
MoH	Ministry of Health
NFC	Near Field Communication
NHS	National Health Service
NWK	Network layer
PHCs	Primary Healthcare Centres
PHY	Physical layer
RBS	Rule Based System
RFID	Radio Frequency Identification
ROI	Return On Investment
RTLS	Real Time Location System
RTTM	Real-time tracking and Monitoring
SECI	Socialisation, Externalisation, Combination, and Internalisation
TOE	Technology-Organisation-Environment framework
WHO	World Health Organisation
WLAN	Wireless Local Area Network
WSN	Wireless Sensor Network
ZC	ZigBee Coordinator

Chapter 1 Introduction

1.1 Introduction

This chapter provides an introduction to the topic of real-time tracking and monitoring technology, for the purpose of improving the Saudi healthcare system by describing current challenges that have motivated the research. The aim and objectives are outlined, followed by a discussion of the research methodology used in the research. The contribution of the research in relation to Saudi Vision 2030 is discussed. The chapter outlines the structure of the thesis through a summary of each chapter.

1.2 Background & Motivation

Healthcare in Kingdom of Saudi Arabia (KSA) has been lagging behind the developed countries of the world, due to the insufficient number of healthcare practitioners and the lack of applications of tracking and monitoring technology. These shortages have contributed to problems such as wasted time and resources, and dissatisfaction with the healthcare system (Al-Moajel et al., 2014; Clifford et al., 2016; Ham et al., 2016). Many of the most prevalent issues are addressed by this research and have motivated it.

Patient misidentification remains as a prominent problem in Saudi healthcare, and can lead to blood and other transfusion errors, lost productivity and lack of reliability in the healthcare system (Aljadhey et al., 2014; Clifford et al., 2016; Dooling et al., 2016). Long patient waiting times contribute to the problems of dissatisfied patients, and stressed hospital staff, which can increase contagion risks and possible patient condition's complications (Strahl et al., 2015). Furthermore, patient waiting times in Saudi Arabia far exceed those of developed countries such as the U.S., with 161 minutes in the Middle East compared with 24 minutes in the U.S. for average waiting time (Mohebbifar et al., 2014; Siciliani, 2014). Inefficient patient flow leads to increased costs, more time required from hospital staff, and delayed procedures (Ham et al., 2016; Rutherford et al., 2017). Additionally, healthcare workforces have not been matching the demand of the growing population, with physician and nurse rates of 16 and 36, respectively, per 10,000 of population (MOH, 2015). The punctuality of physicians has also caused problems in Saudi Arabia, as more than 20% of physicians in a Saudi tertiary care hospital tend to arrive more than an hour late (Clinic Management Department, 2014). Another problem motivating this research is the lack of availability of medical equipment (Almalki et al., 2012; MOH, 2015). A majority of healthcare personnel currently takes up to 60 minutes per shift searching for medical supplies (Ceri et al., 2013), leading to ineffectiveness of procedures and higher costs (MOH, 2015). These problems collectively form a critical deficiency in Saudi healthcare that the application of technology has the potential to solve.

With a population of 33 million, a life expectancy of 74.5 years and a GDP of $1.803 trillion (Saudi General Authority for Statistics, 2018), Saudi Arabia is a major entity in the Arab and Muslim world and has relied on petroleum production for a long time. The KSA also ranked 55 out of 194 nations in the 2010 Human Development Index, and soon thereafter began formalised plans to improve its various services as well as its national income. Recent years have seen the use of e-Health systems in some Saudi hospitals and other healthcare institutions (Alyami et al., 2016), but e-Health systems have remained underutilised (Almuayqil et al., 2015; Alsulame et al., 2015). The Saudi government has indicated that the lack of proper health informatics systems is one of the greatest challenges the healthcare sector currently faces. In 2016 the government unveiled Saudi Vision 2030, which outlined plans for each sector of the government to improve through hundreds of initiatives and objectives (Bhatia & Group Economist, 2016). The Ministry of Health (MOH) is involved in 18 of the 178 objectives provided in the 5-year plan, called the National Transformation Programme (NTP) released in 2016. These 18 objectives spanned various services and processes that demanded many overall improvements. For instance, one of the objectives is to improve the efficiency and effectiveness of the healthcare sector through the use of Information Technology and digital transformation (Saudi Vision 2030, 2016). The national drive based on Vision 2030 has increased active attention to all sectors in the KSA. In regard to the MOH, the plan is ambitious and requires careful consideration for better e-Health utilisation.

The many issues brought forward, combined with the needs established by the Saudi government, reveal a pressing demand for innovative procedures and technologies. Real-time tracking and monitoring systems are the focus of this research, as a solution in resolving these issues and in meeting the demands set by the government in Saudi Vision 2030. Additionally, the existence of hundreds of hospitals across the nation leads to the requirement of a holistic framework that can be applied in any KSA healthcare organisation. In particular, the tracking and monitoring technology system must be able to meet the demands of the local people.

1.3 Aim & Objectives

The aim of this research is to propose and develop a novel smart e-Health system for tracking and monitoring patients, staff and medical assets, to support healthcare decision-making in Saudi Arabia, focusing on RFID and ZigBee technologies. The proposed model will be developed by using knowledge management concepts in relation to knowledge visualisation, to identify an appropriate managerial decision support model for determining the locations and statuses of patients, staff and medical equipment and improving hospitals efficiency and performance.

This aim will be accomplished through fulfilment of the following objectives:

A. To conduct a literature review on:
   - Challenges and barriers of healthcare system in Saudi Arabia.
   - Use of indoor positioning technologies in tracking and monitoring patients, staff and assets in the healthcare environment.
   - Knowledge management concepts in relation to knowledge visualisation and 'Smart' operation in the healthcare sector.
   - Change Management implications and workflow operations improvements in the healthcare environment.

B. To conduct a survey in Saudi Arabia to collect data for assessing current challenges and the potential benefits of developing a system for tracking and monitoring patients, staff and assets in healthcare.

C. To develop a Community of Practice (CoP) of multidisciplinary Saudi healthcare professionals to assess factors that affect the development and adoption of tracking and monitoring technologies in the healthcare environment.

D. To develop a holistic framework for tracking and monitoring systems in Saudi healthcare.

E. To develop a Smart e-Health system to support decision makers, using knowledge management and visualisation concepts to improve patient and staff workflow and medical equipment utilisation.

F. To test, validate and evaluate the proposed system, based on information from a Panel of Experts.

The questions this research aims to answer include the following:

1. What is the optimal information technology system or set of technologies for implementation in Saudi healthcare organisations for improving patient, staff and asset tracking and monitoring when considering cost, efficiency and suitability?
2. How effective is a Community of Practice (CoP) at developing and refining the most suitable information technology system for a Saudi healthcare organisation?
3. What are the steps a Saudi healthcare organisation should follow for successful implementation of a real-time tracking and monitoring technology system?

The concept of triangulation in the research process is the use of multiple approaches to answering a research question to improve confidence in the findings and to provide a more complete understanding of the results (Heale & Forbes, 2013). Further details on the use of triangulation in this research for the provision of more than one independent measure for the research questions will be addressed in the following section.

1.4 Research Methodology

Research methodology is defined as '*the theory of how research should be undertaken, including the theoretical and philosophical assumptions upon which research is based and the implications of these for the method or methods adopted*' (Saunders et al., 2009). Using the 'research onion' developed by Saunders et al. (2009) and shown in Figure 1.1, steps are defined for researchers to perform successful studies. The first step is to determine the research philosophy and what this philosophy requires of the research, followed by the selection of a research approach. From this, a research strategy is formulated with a time horizon specified. Methodology lastly considers the method of data collection and analysis. These steps will be outlined in the following sections.

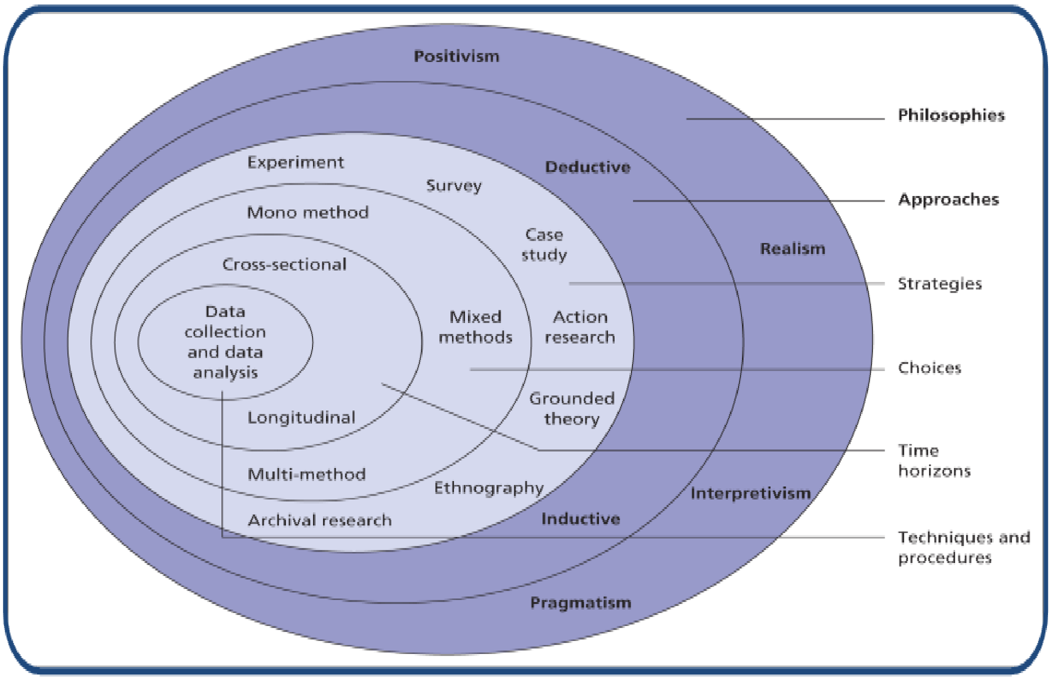


Figure 1.1 The research onion (Saunders et al., 2009)

1.4.1 Research Philosophy

Research philosophy defines the set of beliefs concerning the manner in which data about the phenomena under analysis are to be gathered and analysed (Gray, 2014). The philosophies provided by Saunders et al. (2009) include positivism, realism, interpretivism and pragmatism.

- Positivism argues that reality exists independently and cannot be affected by the researcher (Creswell, 2013; Saunders et al., 2009). An objective viewpoint can explain reality as external and independent of social actors (Saunders et al., 2009). This philosophy utilises statistical or quantitative methods to explain causes and effects of the problem under analysis (Sidorova et al., 2013), and typically uses prior knowledge to test the problems in order to generalise conclusions (Creswell, 2013). Some researchers have argued that positivism is not suitable for more complex problems, particularly in social sciences (Leidner et al., 2009).
- Realism views reality as completely independent from the mind, and applies concepts of natural science for the study of the problem (Mingers, 2006; Saunders et al., 2009). This philosophy considers reality on multiple levels, such that the connections between various social structures can be influenced in the context of the problem (Saunders et al., 2009).

- Interpretivism aims to understand the problem via subjective meanings of social constructs (Creswell, 2013). This philosophy considers subjects as based on the meanings assigned to them by other people in their natural environment, and is typically associated with qualitative methods for data collection (Creswell, 2013; Sidorova et al., 2013). This philosophy allows the researcher to be part of the subject of research, as social constructs can help in understanding the problem (Saunders et al., 2009). However, generalisation of results is often difficult with interpretivism, due to the subjective nature of the participants and researchers (Mackay et al., 2001).
- Pragmatism allows for integration of many assumptions for the phenomenon being studied, and therefore combines one or more philosophies (Saunders et al., 2009). Research approaches can be chosen by the researcher as issues arise during the research, which allows for different perspectives to be obtained (Creswell, 2013). Both quantitative and qualitative methods are usable with pragmatism, and this leads to the ability of the researcher to draw results based on both objective and subjective views (Saunders et al., 2009). Current trends in information systems research indicate more use of pragmatic approaches and result-oriented perspectives (Runeson & Höst, 2009).

This research uses the philosophy of pragmatism, as it requires a mix of positivism and interpretivism in order to capture the problems identified in Saudi healthcare. The objective nature of positivism and its quantitative methods are combined with the subjective beliefs and qualitative methods associated with interpretivism. This chosen philosophy can therefore allow for the development of a holistic framework to approach a solution based on existing frameworks used with regard to adoption of Information Technology systems. Another benefit of this philosophy is the ability to investigate current practices in technology systems' adoption in the healthcare environment. This aids in the development of solutions embedded in a new system. As a technology system affects many aspects of a healthcare organisation, it is helpful that this philosophy considers multiple perspectives such as social constructs and those factors external to these constructs. This results in a focus on practical outcomes from the perspective of multiple realities (Saunders et al., 2009), which helps in providing multiple independent approaches to the first research questions considering the chosen technology system. Therefore, all stakeholders of healthcare organisations, spanning from patients, healthcare professionals and communities are considered in the adoption of future technology systems. This philosophy supports mixed-methods approaches (Creswell, 2013), which is beneficial in this research as user requirements of technology include both personal factors as well as those associated with cost, productivity and efficiency.

1.4.2 Research Approaches

Research approaches are categorised as either deductive or inductive. Deductive research begins with a theory developed from the literature and existing research, experiences and observations. This leads to a hypothesis based on the theory upon which observations are to be made. The research ultimately accepts or rejects this hypothesis. Inductive research begins with observations and then analyses data for pattern, in order for the hypothesis to be formed. The hypothesis is validated and tested in order to form a theory (Saunders et al., 2009).

As this research requires substantial analysis of the literature before forming a hypothesis, it follows a deductive approach. A literature review of both Saudi Arabian healthcare and of existing information systems frameworks is required before developing a new holistic framework and technology system, which this research will then test and validate using Research Strategies.

Research strategies assist researchers in carrying out investigations and are classified as quantitative, qualitative and mixed method approaches (Creswell, 2013; Saunders et al., 2009). Quantitative methods, which apply numerical analyses for objective observation, are used when the relationship between variables or objects must be established or confirmed; whereas qualitative methods, which utilise non-numerical data, are aimed at enhancing the understanding of various social and cultural constructs (Creswell, 2013; Hoe & Hoare, 2013; Tariq & Woodman, 2010).

Quantitative methods are primarily conducted through surveys or experiments (Williams, 2007). Surveys allow for data collection through channels such as online questionnaires, telephone interviews and emails. Analysis can be carried out through descriptive and statistical techniques (Saunders et al., 2009; Gable, 1994). Experimental research employs comparisons between the actual and expected results of experiments (Saunders et al., 2009).

Qualitative methods are typically carried out through grounded theory, case study research, action research, ethnography and archival research. These methods aim to discover new issues by analysing the implications for people affected by the problems (Hoe & Hoare, 2013). Non-numerical data includes interviews, observation, semi-structured interviews and focus groups.

Mixed methods research strategies utilise both quantitative and qualitative methods together, to better understand the identified problems. They therefore use data of both numerical and non-numerical form, and include components of objective and subjective analysis (Creswell, 2003; Tariq & Woodman, 2010).

Triangulation, mentioned previously, can use multiple sets of data on the same phenomenon or use multiple data collection methods (Heale & Forbes, 2013). This research is a mixed methods research strategy, as the study demands several components to be analysed separately in the form of primary and secondary data to obtain more than one perspective on the issue of real-time tracking and monitoring systems, on Saudi healthcare issues and on the holistic framework developed. These forms of data are analysed with the following methods:

- A literature review was conducted on the topics of Saudi healthcare (Chapter 2), indoor positioning systems (Chapter 3), Information Technology adoption frameworks (Chapter 4), knowledge management and knowledge visualisation (Chapter 7). This is secondary research of a qualitative nature. The use of several branches of academic study allows for the multiple approaches of triangulation to be implemented and therefore increases the confidence in the resulting framework chosen.
- A Community of Practice (CoP) consisting of multidisciplinary healthcare professionals from Saudi Arabia was formed in order to determine the set of factors and user requirements affecting the adoption of health information systems in KSA. This is categorised as primary research, fitting a qualitative method, and is discussed also in the context of the development and validation of holistic framework for tracking and monitoring systems in Chapter 4.
- A questionnaire survey was conducted, using online distribution and completion methods, in order to assess the need for tracking and monitoring systems, and to refine the developed framework. This is primary research of a quantitative type and is described in Chapter 5.
- Proof of concept trial experiments and simulations' scenarios were carried out on the ability of ZigBee technologies to meet the expectations described in the literature review and to validate the ability of the system to achieve success. This is primary research of a quantitative form and is described in the context of hospital workflow improvement in Chapter 6.
- A panel of experts was utilised to evaluate the real-time tracking and monitoring technology system that was developed through this research. The panel consisted of 10

healthcare professionals with at least 5 years of experience in the healthcare sector. These participants came from three hospitals and included backgrounds in management, engineering, Information Technology (IT) and healthcare (nurses, doctors). The use of the panel is primary research, fitting a qualitative method, and is discussed and analysed in Chapter 8. Validation and evaluation of the system provide support for the accuracy of the claims made by the CoP for both the technology system and for the holistic framework such that the proposed answers to the second and third research questions are more reliable.

- Triangulation was achieved through the mixed methods research strategy in several ways. The literature review is a qualitative study that provided clarity on the many costs and benefits of each type of technology while the CoP, also qualitative in nature, determined the set of relevant factors for implementation of the technology in healthcare. These perspectives ensure that both academic resources and practices resources align their knowledge base and expectations. The use of the CoP and the questionnaire refine the holistic framework using both a qualitative (CoP) and quantitative (questionnaire) research strategy, and both use current and practical perspectives on the issues raised. The technology system chosen based on this research was validated quantitatively through simulation in laboratory and hospital settings, and was further validated and evaluated qualitatively through a panel of experts.

The complete research methodology is summarised in Figure 1.2.

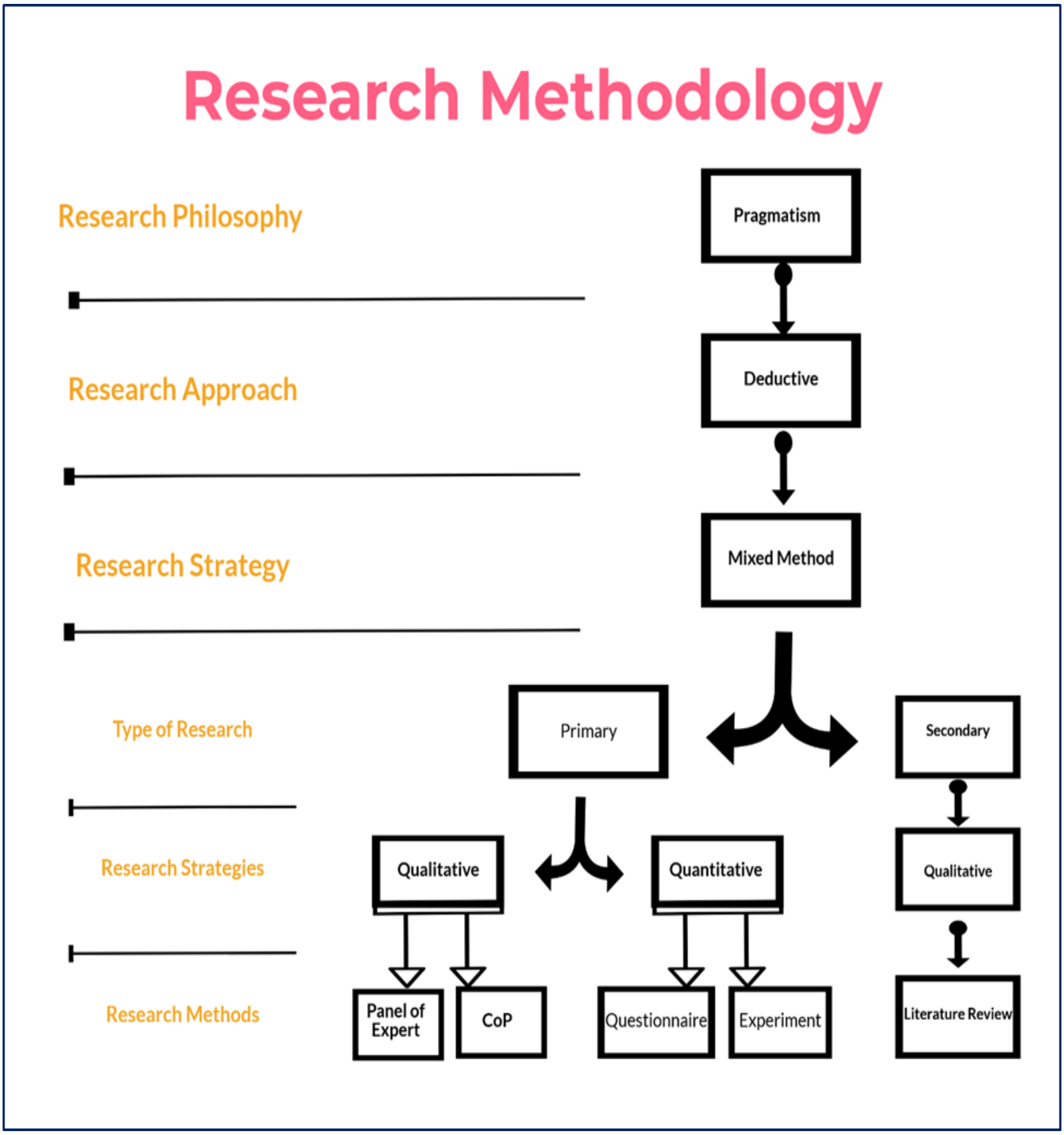


Figure 1.2 Research methodology

1.4.3 Research Design

This research was carried out to provide solutions to the problems and to achieve the objectives identified at the beginning of this chapter, following steps:

- The topic of developing a real-time tracking and monitoring system was formulated and clarified.
- A literature review was conducted on Saudi Arabia, Saudi healthcare and its most prominent issues.

- A literature review was conducted on the various indoor locating technologies with focus given to RFID and ZigBee, as these technologies appeared most promising after the initial review.
- A literature review was conducted on theoretical frameworks and models related to technology adoption in healthcare, leading to emphasis on technology, organisational, human and business contexts.
- A holistic framework for the adoption of a real-time tracking and monitoring technology system was developed for the purpose of supporting healthcare decision makers, using factors identified from the literature reviews.
- A Community of Practice (CoP) was formed consisting of various healthcare professionals situated in Saudi Arabia for the establishment of all factors and user requirements relevant to the adoption of technology systems in healthcare. This led to the first refinement of the holistic framework.
- A questionnaire was developed, a pilot was tested with specialised healthcare individuals, subsequently amended, tested statistically for internal consistency in language and content, and then distributed through social media channels, such as WhatsApp per the 'snowball' method (Voicu & Babonea, 2007). Analysis of the questionnaire results led to the second refinement of the holistic framework.
- Proof of concept trial experiments and simulation scenarios were conducted for performance testing of ZigBee technology.
- A real-time tracking and monitoring (RTTM) system was developed for the purpose of providing solutions for the tracking and monitoring of patients (addressing patient flow and patient satisfaction), staff (addressing response time and physician punctuality), medical equipment (addressing the issue of their availability and inventory management) and maternity unit, provided with mobile wayfinding and indoor navigation, and a hospital performance dashboard and a hospital staff training and learning tools.
- The proposed system was validated by two proof of concept trial experiments and evaluated by a panel of experts consisting of 10 healthcare professionals, each with at least 5 years of healthcare experience.

A summary of the step-by-step research design is provided in Figure 1.3.

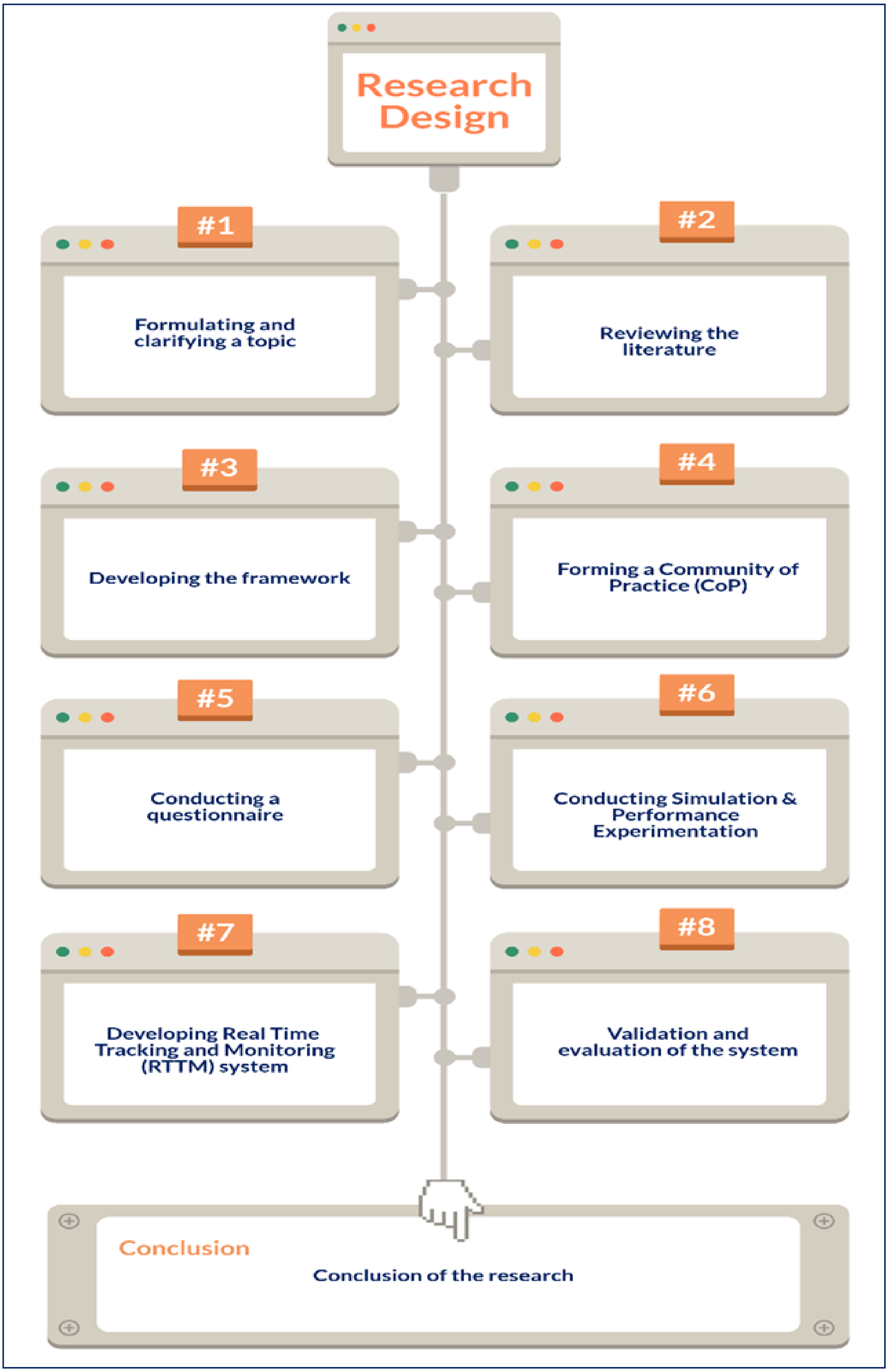


Figure 1.3 Research design

1.5 Research Challenges

The challenges arising in this research are most likely to be linked with predictable factors as detailed as follow:

- The research is broad in scope and aims to apply concepts to the whole of the Saudi healthcare system. The Saudi healthcare system is complex, and a framework applicable to all healthcare organisations may prove to be of the greatest difficulty. Although the research aims to provide a framework that can be adapted by any healthcare organisation within Saudi Arabia, a one-size-fits-all framework is beyond the scope of an individual research project and is likely to require additional adjustments as new developments take place within the governmental (legal) level, the economic level and the social level.
- People's attitudes toward the framework will change by region, over time and at the individual level, yet its success demands a fair amount of acceptance by its user base. A survey can alleviate the pressures placed by people with differing opinions, but there are many unpredictable aspects of information systems implementation when considering a variety of jobs and organisational structures. Although consensus on a technology can be beneficial for decision making, outlying opinions provide insight on places for improvement; this research is limited in its inability to capture future outlying opinions during real implementation of the developed framework.
- The publication of the National Transformation Programme (NTP) in 2016 outlined a five-year plan that may lead to accelerated and unpredictable changes in Saudi healthcare. The objectives given to the Ministry of Health (MOH) may place great burden on the healthcare sector, to which this research must adapt within the given time scale.
- The research was conducted while the researcher remains in the UK, while the study concerns the KSA. Additionally, the healthcare professionals coordinating with the researcher are all located in the KSA.
- Receiving consistent cooperation of healthcare professionals during this research could have led to unexpected barriers in information that could stunt the researcher's efforts or lead to information bias.

1.6 Research Contribution

Achievement of the aims of this research will lead to the following contributions:

- Literature reviews of:
    - The challenges and barriers of the Saudi healthcare system
    - The use of indoor positioning technologies in a healthcare environment
    - Theoretical frameworks related to the adoption of Information Technology systems
    - Knowledge management with a focus on the SECI model
    - Knowledge visualisation and Smart operations in healthcare
    - Change management and healthcare workflow improvements
- Development of a sound holistic framework for the support of healthcare decision makers
- Establishment of a Community of Practice (CoP) consisting of Saudi healthcare professionals
- A survey of the most influential barriers and benefits of developing tracking and monitoring systems in healthcare through a questionnaire with Saudi participants
- Simulated and experimental results that validate the technologies for the tracking and monitoring system
- Development of a reliable Real-Time Tracking and Monitoring (RTTM) system for healthcare in Saudi Arabia
- A visualised knowledge by the RTTM system for continual hospital workflow improvements.

1.7 Validation and Evaluation of Research

Validation is ‘*the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model*’ (Oberkampf & Trucano, 2007), and is essential to the assurance that the framework and system meet their intended purposes (Beecham et al., 2005). The purposes identified for this research include the improvement of healthcare organisational efficiency, productivity, reliability and accountability, which intend on addressing the many problems identified at the beginning of this chapter. There are several validation procedures that have been performed throughout this research and are presented in Table 1.1.

Table 1.1 Validation procedures used in the research

Validated item	Definition	Conducted test or method
Content Validity	The degree to which questionnaire content represents the topic being measured (Lian, 2017).	• Expert opinion
Questionnaire Construct Reliability	The degree of internal consistency between the variables in each construct (Hung et al., 2010).	• Internal consistency assessment using Cronbach's alpha
Validity of the holistic framework	The process of ensuring that the holistic framework actually meets the purpose for which it was intended (Williams et al., 2012).	• CoP
Validity of the system	The process of ensuring that the system actually meets the purpose for which it was intended (Beecham et al., 2005).	• Panel of Experts • Proof of concept trial experiments

The content of the research as a whole was validated through the various methods as outlined in Table 1.1. The content of the questionnaire was validated through expert opinion in the pilot testing stage. The reliability of the questionnaire was validated through the internal consistency assessment using Cronbach's alpha. The validity of the holistic framework was done through CoP. The proposed system was validated through the panel of experts and a proof of concept trial experiments.

1.8 Research Ethics

The Staffordshire University's code of ethics was followed throughout the entire research process. The questionnaire included responses from hundreds of participants in Saudi Arabia. On the cover of the questionnaire, the participants were informed of their rights and approval of consent through inclusion of the following statements:

- DO NOT participate in this questionnaire if you are vulnerable to coercion or undue influence (e.g., unable to consent, less than 18 years, prisoner, etc.).
- All answers will be treated in confidence and names of participants are not required.
- You can stop at any time during the questionnaire.

- While your cooperation in answering every question will help us understand important, you are not obligated to answer every question.
- Your participation in this questionnaire is voluntary.
- If you agree to participate, you can withdraw from participation at any time without any consequences (incomplete and dropped questionnaires may be used).
- There are no direct benefits to you for participating in this research.
- There are no risks associated with participation.
- By your return of the completed questionnaire, you consent to participate in this study.

As the questionnaire was distributed in both English and Arabic, all participants were informed of their consent, confidentiality and anonymity. The research results will only be published in academic publications.

1.9 Research Structure

This thesis is structured by nine chapters as shown in Figure 1.4 and outlined as follows:

Chapter 1 **Introduction**: The motivation for this research is identified through the many persistent problems in Saudi Arabian healthcare, followed by its aim and objectives, research methodology and contributions.

Chapter 2 **e-Health and Healthcare Challenges**: Current healthcare challenges and barriers in Saudi Arabia are discussed, followed by an overview of Saudi Vision 2030 and the five-year plan provided by the NTP.

Chapter 3 **Using Technology to Track and Monitor Patients, Assets and Staff**: Indoor locating and real-time tracking technologies are overviewed, including a description and comparative analysis of RFID, ZigBee, Bluetooth, cameras, infrared, WLAN/Wi-Fi, near-field communication (NFC) and ultra-wideband. Smart hospitals are overviewed with regard to these technologies. RFID and ZigBee are given more detailed analysis through literature

reviews.

Chapter 4 **Development of a Holistic Framework for Tracking and Monitoring Systems in Saudi Healthcare**: The concept of a framework is overviewed followed by a review of theoretical frameworks related to the Information Technology systems being developed for this research. These related frameworks include the Information System Strategy Triangle (ISST) and the Human, Organisation and Technology-fit (HOT-fit) factors frameworks. A holistic framework is developed utilising the technology, organisational, human and business contexts, and an adoption strategy for the framework is developed. The concept of Communities of Practice (CoP) is outlined, followed by a discussion of the influence of the CoP developed for this research on the factors and user requirements for technology adoption in Saudi healthcare. Change management is overviewed and the holistic framework is refined.

Chapter 5 **Necessity of a Tracking and Monitoring System in Saudi Hospitals**: The questionnaire is described in terms of its design, pilot testing and administration. The data collected from the questionnaire are analysed and the holistic framework is further refined.

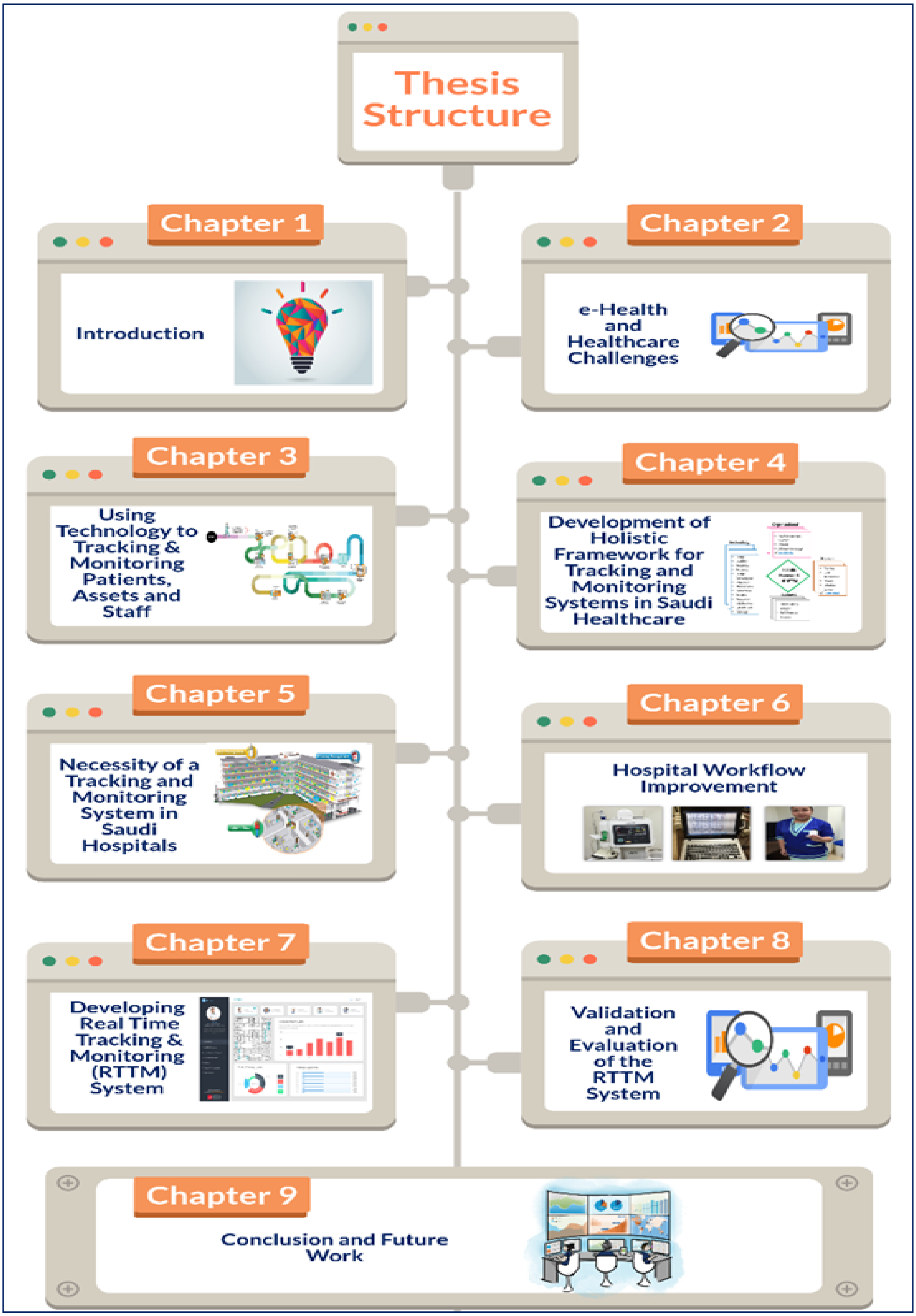


Figure 1.4 Thesis Structure

Chapter 6 **Hospital Workflow Improvement**: Workflow challenges in Saudi healthcare are discussed using literature on workflow improvements to identify methods for this research to utilise. The first part uses simulation scenarios to address workflow improvements, providing four scenarios leading to reduced workflow bottleneck times. The second part uses a revised patient visit scenario and tests it through two proof of concept trial experiments. The first experiment examines the ability of ZigBee to accurately track motion of an individual in a laboratory setting. The second experiment compares search times for staff and medical assets in a Saudi hospital.

Chapter 7 **Knowledge Management Transformation by a Real-Time Tracking and Monitoring (RTTM) System**: A literature review is conducted on knowledge management with emphasis given to the SECI model and its application. Knowledge visualisation is reviewed and subsequently applied to the RTTM system for Saudi healthcare improvements. The developed system using knowledge management and data visualisation concepts is outlined in various tracking and monitoring applications, extending beyond patient and staff, and including mobile wayfinding and indoor navigation, a hospital performance dashboard and a hospital staff training and learning tools.

Chapter 8 **Validation and Evaluation of the RTTM System**: Validation of the proposed system is discussed, based on the results of the two proof of concept trial experiments performed in Chapter 6. The panel of experts and design of the evaluation are discussed, followed by an analysis of the results of the panel's evaluation and recommendations for improvement.

Chapter 9 **Conclusion and Future Work**: A summary of the research is given with discussion of the contributions, limitations and challenges of the research. Ideas for future work are also presented.

1.10 Conclusion

This chapter has provided an introduction to the topic of tracking and monitoring technology to improve the Saudi healthcare system by describing current challenges that have motivated the research. The aim and objectives have also been given, followed by a discussion of the research methodology adhering to the research onion developed by Saunders et al. (2009). The expected contribution of the research, its validation and ethics considerations are also provided. The outline has shown the structure of this thesis through a summary of each chapter. The next chapter expands on the challenges in Saudi healthcare that have been introduced alongside a discussion of Saudi Vision 2030.

Chapter 2 e-Health and Healthcare Challenges

2.1 Introduction

This chapter reviews the following items:

1) Challenges confronting healthcare and e-Health in Saudi Arabia, such as patient misidentification, waiting times, performance, efficiency, workforce, and late doctor's arrival (Section 2.2).

2) An overview of the demographics and economic patterns of Saudi Arabia (Section 2.3.1).

3) Current progression of the healthcare system and e-Health practices in Saudi Arabia, comparing those with the current UK healthcare system status (2.3.2 & 2.3.3)

This chapter then discusses (Section 2.4) the program "Saudi Arabia vision 2030" (vision 2030), and illustrates its expected impact and relevance for the KSA healthcare sector over the coming years.

2.2 Healthcare challenges

There are many challenges, both past and ongoing, arising in the implementation of healthcare systems, services and applications in developing countries, such as Saudi Arabia (Aljuaid et al., 2016). Recent efforts have demonstrated a great need for a more advanced methodology and approach for these countries' healthcare systems (Alkadi, 2016). Over the past few years, e-Health systems and applications have started being implemented across Saudi Arabia in both hospitals and other health institutions, though they remain under-utilised (Alaboudi et al., 2016). The Health authorities and the Reform Committee identified lack of proper information systems as one of the major challenges in healthcare (Yusuf, 2014).

2.2.1 Patient Misidentification

Patient misidentification is a prominent issue in the healthcare sector. The consequences of patient misidentification range from transfusion errors to death (Clifford et al., 2016). Proper identification of patients, prior to the provision of any services, is considered crucial to avoid any wrong-patient errors at any stage of care (Watban, 2015). In Saudi Arabia a 12-year-old girl, who was admitted to a Saudi hospital for sickle cell anaemia, was mistakenly given HIV-tainted blood during a transfusion (Hazzazi, 2018). Khoja et al., found in their review of 5,299 prescriptions from public and private clinics in Saudi Arabia that 18.7% had errors that ranged from trivial to serious (Khoja et al., 2011). A different study in the paediatric Intensive Care Unit at King Abdulaziz Medical City in Riyadh, Saudi Arabia, which reviewed 2,380 medication orders, found the error rate to be 56 per 100 orders (Al-Jeraisy et al., 2011). In one tertiary care hospital in Saudi Arabia, patient misidentification constituted 3.1% of the reported patient incidents (Aljadhey et al., 2014). This is a worldwide problem, as a survey in the U.S. reported that 64% of respondents believed that patient misidentification occurs frequently. Furthermore, in the US, 86% of executive hospital staff and healthcare providers witnessed medical errors as a result of patient misidentification. This issue alone results in 28.2 minutes wasted per shift per clinician (Commission, 2015). Another type of patient misidentification is that babies may be switched at birth. Currently, there are no national statistics on the number of such cases in Saudi Arabia, but local news in Saudi Arabia reported that cases of babies switched at birth have increased (Mekki et al., 2018; Gazette, 2016; Arabiya, 2016; Al Bawaba, 2014). Some hospitals apply bands with number written using black ink, or bracelets with a 10-digit number (as seen in Figure 2.1) around new-born babies' wrist as an identification, while many hospitals do not.

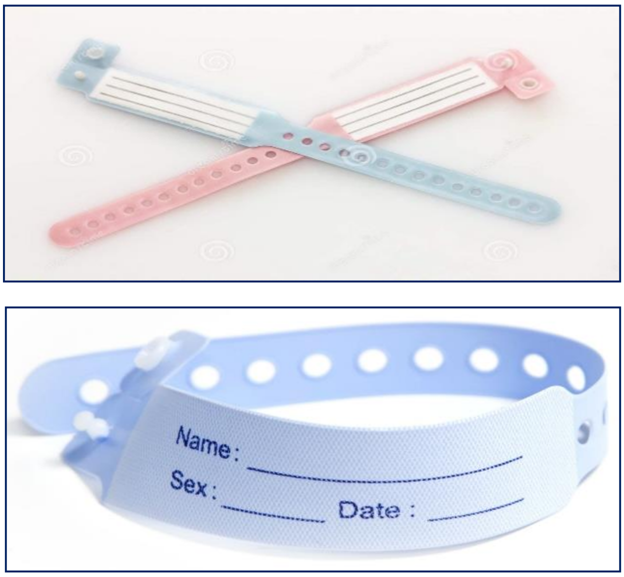


Figure 2.1 Hospital ID Bracelets

At the moment, most healthcare providers in Saudi Arabia use a manual method to identify the babies and matching them with the mother. Unfortunately, there is no electronic recording of patient/babies entry and exit to wards/units in Saudi hospitals (Alharbe & Atkins, 2016). There is a clear need to use advanced security and electronic solutions to aid in the matching of new-borns to their mothers, and for abduction prevention purposes (Paaske et al., 2017; Chang et al., 2016). Tracking and measurements systems, such as ZigBee and RFID tags, are required to prevent babies from being taken from hospitals or being mismatched (Al-mahadeen, 2015; Alharbe & Atkins, 2016; Chang et al., 2016). Tracking technologies such as RFID have the ability to capture data automatically without human intervention. Compared to barcode scanning, RFID does not require line-of-sight for readers to capture information from tags. Also, barcode readers can only analyse one piece of data at a time, whereas RFID technology consists of a microprocessor that can track a large amount of data wirelessly, without ever having to connect to a reader device. (Paaske et al., 2017). In the US, financially, the patient misidentification issues add up to $900.000 per year per hospital in lost productivity (Dooling et al., 2016).

This issue is of great importance worldwide, and valuable data and experience can be gathered from several countries. One U.S. hospital's emergency department reported that 97% of clinicians (66 out of 68) witnessed chart errors, or medical information being attributed to the wrong patient, within the past 3 months (Yamamoto, 2014).

In the UK, the National Patient Safety Agency reported that more than 42% of total incidents in the NHS were due to patient identification errors. Monthly, more than 500 patients admitted through A&E resulted in misidentification that led to incorrect medications, GP details, and medical records/notes (See Figure 2.2). Patients were treated and received incorrect medications for diseases such as asthma when not asthmatic (ECRI Institute Patient Safety Organization, 2016). Preventable medical errors were caused by mistakes such as traditional patient identifiers, like oral demographic data, or patients' addresses that can be easily mistyped.

Digital methods, such as tracking and monitoring technologies, can help in preventing such errors effectively (Hassan, 2016). These kinds of errors have been attributed to an estimated 440,000 deaths per year in the U.S. alone, ranking as the third leading cause of death (Makary & Daniel, 2016).

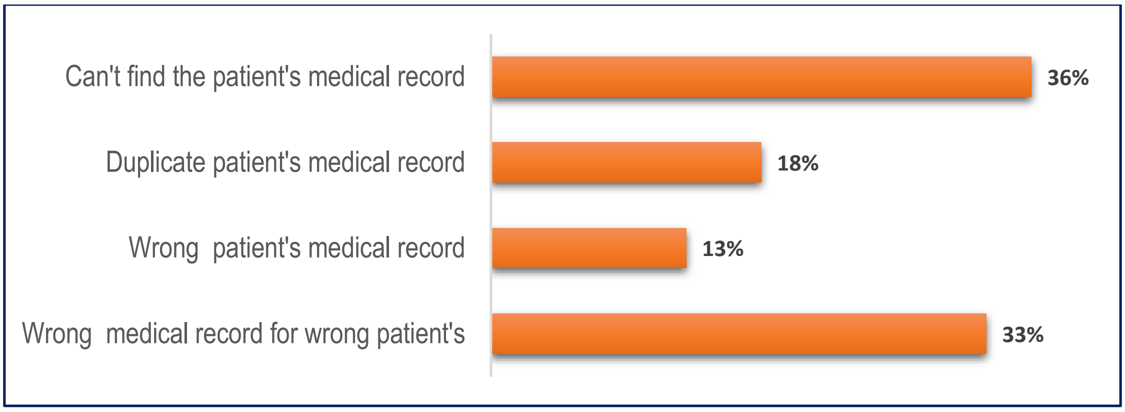


Figure 2.2 What leads to patient identification error? Source :(Ponemon Institute, USA, 2016)

Researchers conducted a study, using RFID technology, to authenticate patients and medical staff during interventions such as medication administration and blood sampling. The study evaluated whether or not the RFID identification and confirmation methods were efficient and effective in the prevention of medical errors. The results of this study showed that the system correctly identified medical staff, patient ID, and medication and blood sampling data in real time. Also the result showed an increase in patient identification verification from 75% pre-implementation, to 100% post-implementation (Paaske et al., 2017).

Suggestions for guidelines on reducing patient misidentification have come from many organisations, such as the National Patient Safety Agency, the Joint Commission on Accreditation of Healthcare, and the World Health Organization. Their recommendations include

1- Using new technologies and safety checks at automated-systems level, to reduce errors and improve monitoring.
2- Improving the design of physical, electronic, and assigned patient identifiers, to decrease patients' misidentification (Jo, 2014).

RFID systems can make it easy to detect human errors that might lead to unacceptable adverse events (e.g. wrong patient, wrong site, wrong procedure) (Zhao et al., 2014). Both RFID and ZigBee technologies have proven to improve substantially the error detection, with the added benefit of real-time monitoring in departments and clinic-wide processes, ranging from administration to the tracking of blood and pathology samples (Ajami & Rajabzadeh, 2013; Alharbe et al., 2013; Lai et al., 2014; AlYami et al., 2016).

2.2.2 Waiting Times

Long waiting times before being seen by a doctor is another prevalent issue in healthcare, which results in dissatisfied patients, stressed hospital staff, increased contagion risk, and possible complications for patients with chronic conditions (Strahl et al., 2015).

In outpatient clinics in the U.S.A, average waiting time is 24 minutes (Siciliani, 2014), while research shows average patient waiting time in outpatients clinics in the Middle East region, including Saudi Arabia, is 161 minutes (Mohebbifar et al., 2014). A survey carried out in Saudi Arabia, showed that 38.5% of respondents believe hospital visits take a long time, and this is one of the most common patients' complaints (Al-Moajel et al., 2014, The Patients Association, 2016). In 2015-2016, patients' complaints concerning waiting time numbered 4,078 (Carter, 2016).

In the UK, the recent 16% annual increase in emergency admissions to NHS hospitals corresponds with 4,800 more A&E daily patient admissions than 5 years ago, and treatment waiting lists have risen 47% faster than the population over the same period. This has resulted in the percentage of patients spending more than 4 hours in NHS A&E to increase from 5.6% in 2012 to 16.5% in 2017 (see Figure 2.3). Similarly, waiting times for consultant-led treatment have been above the 18-week target in early 2016, and have not yet dropped (Baker, 2018).

Key	
2.0%-3.5%	Meeting target
3.5%-5.0%	
5.0%-7.0%	Breaching target
7.0%-9.0%	
9.0% - 11.0%	
11.0% or more	

	2011	2012	2013	2014	2015	2016	2017
Jan	4%	4%	5%	5%	9%	11%	15%
Feb	3%	5%	6%	5%	8%	12%	12%
Mar	3%	3%	6%	4%	7%	13%	10%
Apr	3%	4%	7%	5%	7%	10%	10%
May	3%	3%	3%	5%	6%	10%	10%
Jun	3%	3%	3%	5%	5%	9%	9%
Jul	2%	3%	3%	5%	5%	10%	10%
Aug	3%	3%	4%	5%	6%	9%	10%
Sep	3%	3%	4%	5%	7%	9%	10%
Oct	3%	4%	4%	6%	8%	11%	10%
Nov	3%	4%	4%	7%	9%	12%	11%
Dec	4%	5%	5%	10%	9%	14%	15%

Figure 2.3 Patients spending 4+ hours in A&E, 2011-2017, NHS all departments-UK

Patients begin to feel frustration and anxiety at different points in time while waiting to see a doctor, and more than 60% report that these feelings arise after 30 minutes (see Figure 2.4). The ability to meet patients' expectations on waiting time improves their general satisfaction of their healthcare experience, and can lead to a better relationship with the healthcare providers, thus improving their continued care, and ultimately their health (Al-Abri & Al-Balushi, 2014). Patient-centred medical practices seek to make patients feel better, both physically and emotionally (Pomey et al., 2015).

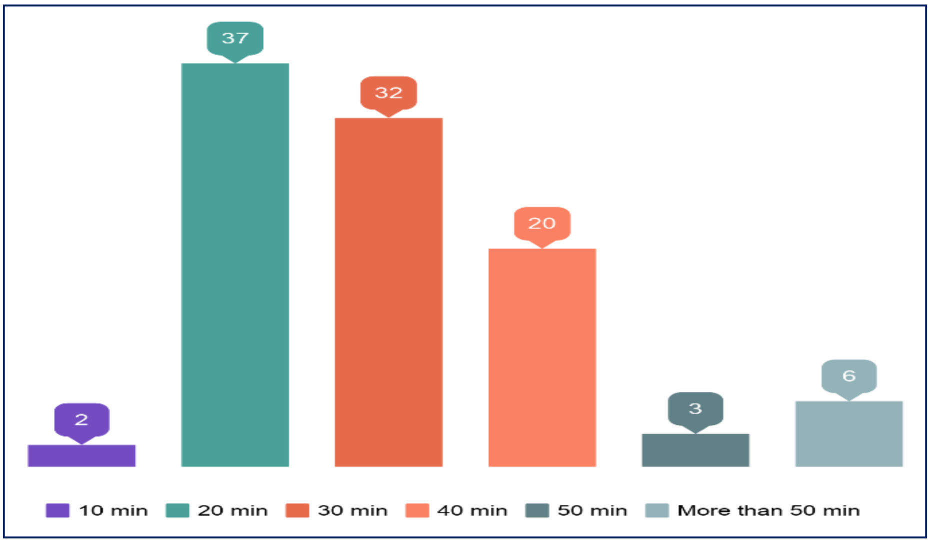


Figure 2.4 How long it takes for patients to feel wait time frustration? (USA)

2.2.3 Patient Flow

While healthcare systems are making progress toward more value-based, patient-centric care practices, the majority of hospitals are experiencing significant operational and financial stresses (Mold, 2017). Diversions, long waits, and delays in the emergency department (ED) are part of the patient flow issues. 'Patient flow' refers to how well a healthcare system can manage patients with both effectiveness and efficiency in mind (NHS, 2017). Patient flow includes all process of attending to patients, from the time they walk into a medical facility to the time they check out for discharge (See Figure 2.5).

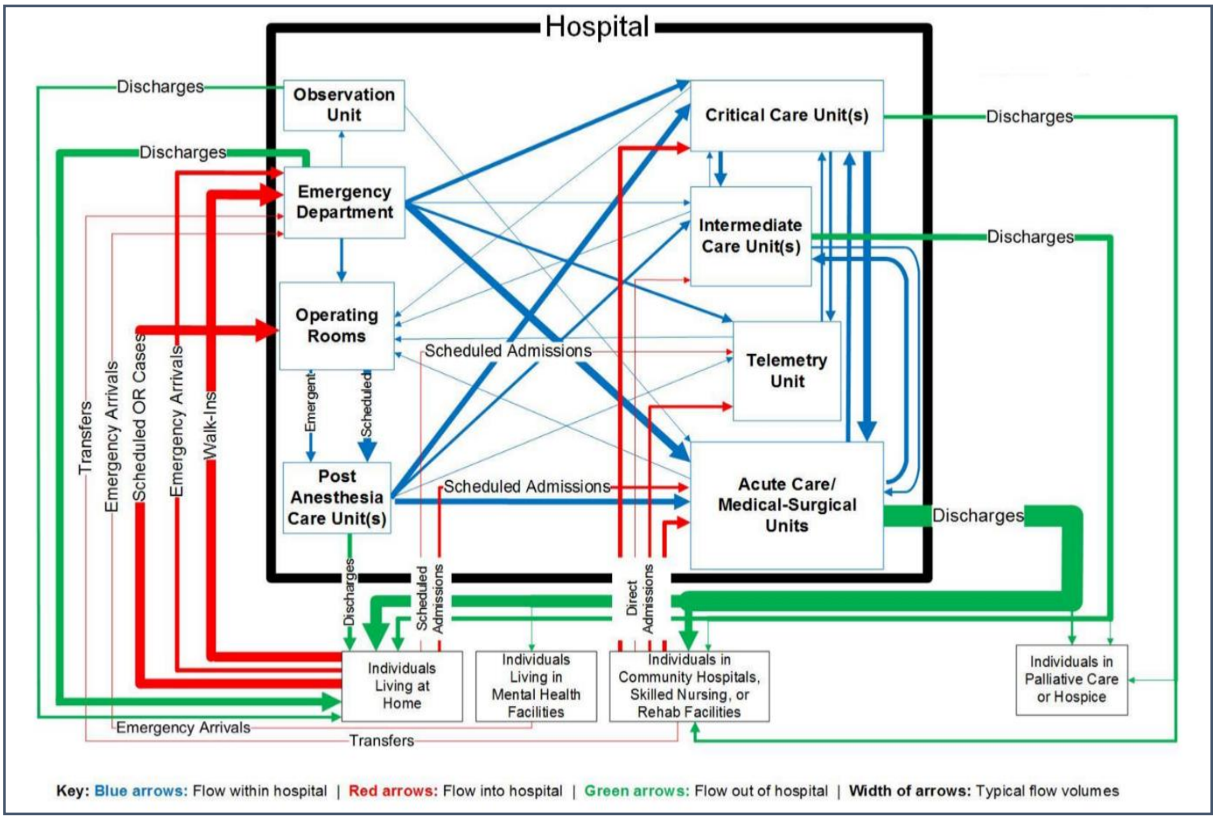


Figure 2.5 System Map of Patient Flow in Hospital. Source: Rutherford et al., 2017)

When patient flow is poor, costs increase, caused by more time and effort required from hospital staff, and safety is also jeopardised (Ham et al., 2016). Delays are often the result of ED beds being occupied by patients waiting for admission to the hospital.

Hospital issues are due to mismatches between the bed and staff capacity, and the demand for various clinical services. They also include inefficient processes for transferring patients among units and for discharging patients, and also long wait time for transferring patients to skilled nursing and to long-term care settings. Lack of inpatient capacity also results in delayed or cancelled surgical procedures. Inadequate patient flow results in suboptimal patient care and increases the risk of harm to patients (Rutherford et al., 2017).

In the UK, delays in patients discharge cost the NHS £900m per annum. Delayed discharges lead to longer waiting times, due to a lack of patient beds for new admissions (Carter, 2016). In recent years, the NHS has consistently missed its target of processing 95% of patients through A&E within 4 hours, increasing the burden and stress on hospital staff by aggravating the factors related to increased waiting time (Karakusevic & Edwards, 2016) – See Figure 2.6.

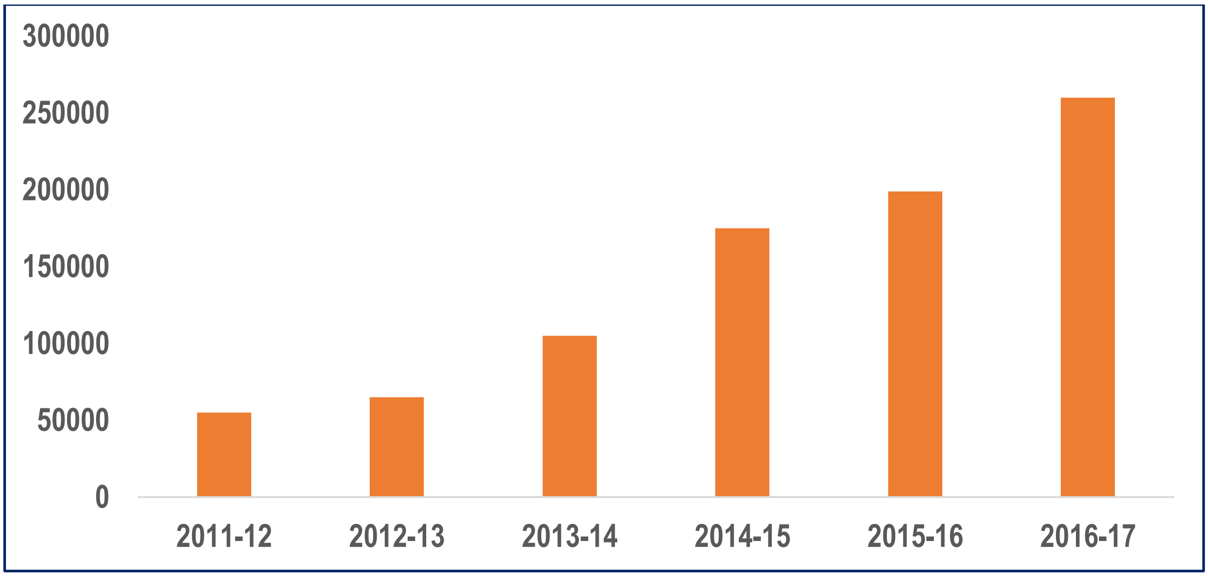


Figure 2.6 Number of Patient waiting over 12 hours (2011-2017). Source: NHS (UK)

Proper patient flow results in reduced costs, better access to services, improved quality of care, greater flexibility in admissions numbers, and improved efficiency and accuracy in the processes and quality of patient care. It has been shown that, health systems and applications can enhance and improve patient flow, which corresponds with improved throughput and continuity, while reducing patient processing times (Furterer, 2014; NHS, 2017). The Cambridge Hospital ED implemented a project for the improvement of patient flow, and the project positively affected all metrics measured. The assigned team implemented a tracking system to optimise patient care and experience, by improving patient flow. They applied mix methods, by using tracking of patient activities, and developing a patient care timeline. Within 9 months of implementation, ambulance diversion dropped from a mean of 148 hours to 0 hours (in a three-month period), and total length of ED stay dropped from 204 minutes to 132 minutes on average; patient volume subsequently increased by 11%. ED-compliance raised from 71% to 97%, and patients that left without being seen (LWBS) fell from 4.1% to 0.9% (Sayah et al., 2014).

Almomani & AlSarheed (2016) analysed Saudi Arabian hospitals patient flow issues. The Figure 2.7 shows an analysis for the root causes that affect patient flow in Saudi hospitals. Their study indicated that one of the main issues is to improve the patient flow process. The major challenge with this issue is a lack of patient flow policies and procedures in Saudi Arabian hospitals. (Almomani & AlSarheed, 2016). Another issue, outlined by this study, is a lack of measuring tools, such as real-time data, KPIs and dashboards, to help healthcare personnel and decision makers in the hospitals. Tracking and indoor location technologies, such as RFID, can provide effective measurement tools in real time, and manage the massive data generated from the reader and tags (Kwon et al., 2014).

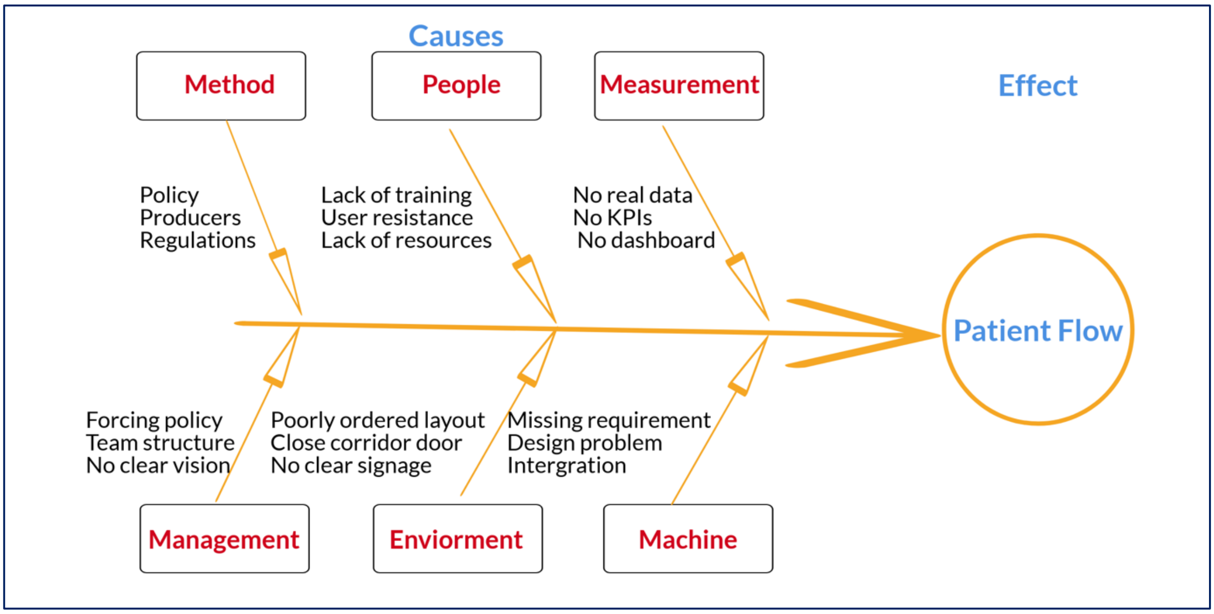


Figure 2.7 Analysis for the root causes that effect patient flow in Saudi Hospital. Source: (Almomani & AlSarheed, 2016); modified by author.

Managing patient flow is a day-to-day activity. However, as advised by organisations and research bodies such as the Institute for Healthcare Improvement, this activity should be coupled with smart systems that skilfully identify problems and develop prevention strategies to avoid future problems (Rutherford et al., 2017). The U.S. Department of Health and Human Services and the Food and Drug Administration, strongly recommend and encourage the adoption of Health Information Technology (HIT) and the development of effective real time monitoring systems (Paaske et al., 2017). The Real-Time Flow System (RTFS) is based on effective management principles, and makes it possible to measure flow (capacity and demand) on a real-time basis, and to take actions based on these measurements to maintain better flow (Bean et al., 2017).

2.2.4 Healthcare Workforces in Saudi Arabia

Growth in the number of healthcare facilities and infrastructure in Saudi Arabia has not been matched by the increase in personnel, resulting in a shortage of physicians, nurses and pharmacists. Since most personnel are foreign professionals, turnover is high and the workforce is unstable. The Ministry of Health (MOH) gives a figure of 248,000 for the total healthcare workforce in Saudi Arabia, and only 38% of this workforce is of Saudis nationality. Physician and nurse rates per 10,000 of population in Saudi Arabia are 16 and 36, respectively, which is lower than in most neighbouring and other countries in terms of physicians, and much lower in terms of nurses, as shown in Figure 2.8 (Ministry of Health, 2017).

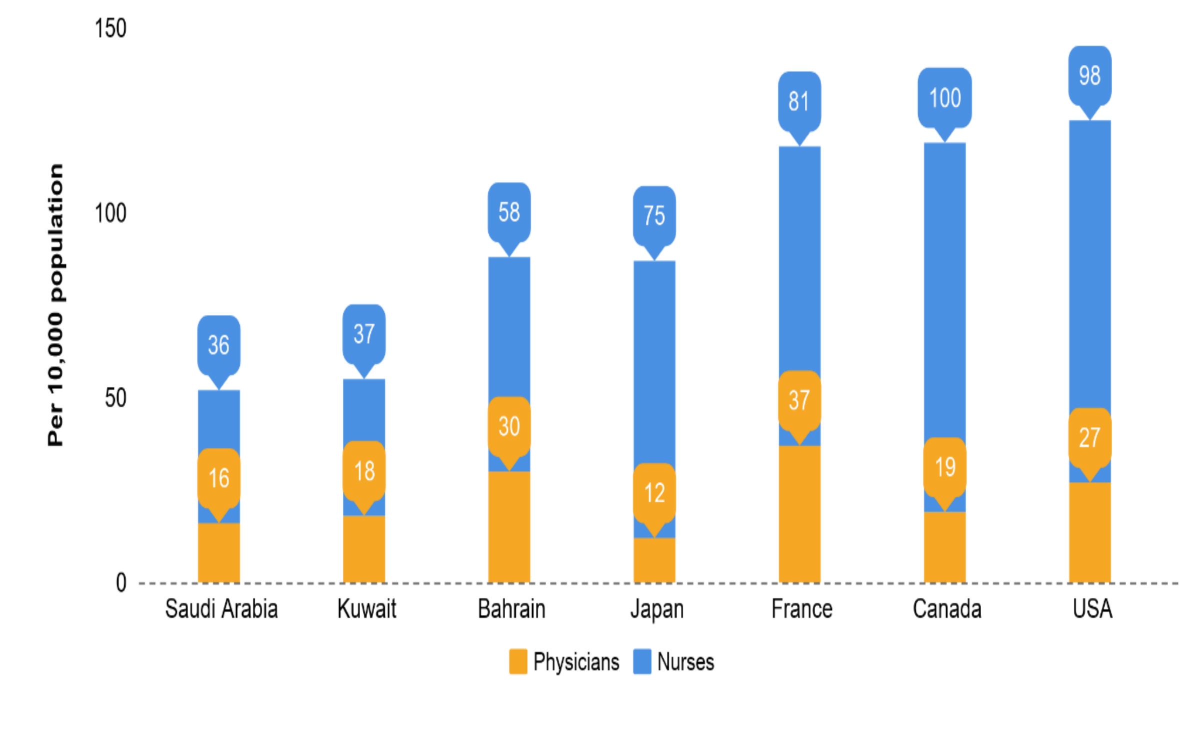


Figure 2.8 Comparison of number of physicians and nurses per 10,000 population.

Most personnel are foreign, which means there is a large turnover, and therefore workforce instability. The deficit is met by bringing in foreign recruits, some of whom come from the USA, UK and Australia, and with most nurses being recruited from India, the Philippines, South Africa, Malaysia and the Middle East. A research demonstrated that at one of the largest Saudi Arabian hospitals, 95% of nurses originated from over 40 different countries outside of Saudi Arabia (Pines et al., 2011). However, in developed countries, e.g. NHS (UK), 87.6% of staff are British and less than 13% are nationals of other countries – see Figure 2.9 (Baker, 2017). This raises issues of extensive induction courses and training, and therefore digital systems are needed to facilitate and bridge the language and cultural gaps.

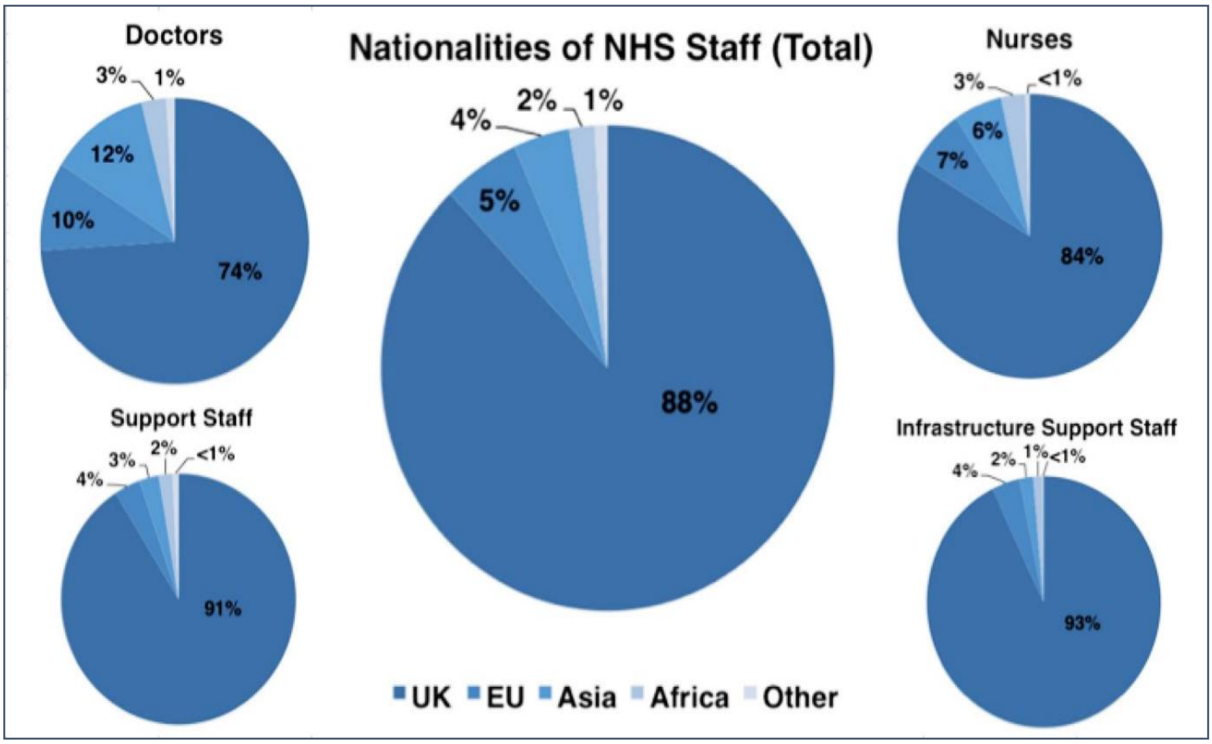


Figure 2.9 Nationality of NHS staff (UK). Source: NHS Digital, 2018

At the present moment, it is necessary to employ many foreign nationals for working in healthcare in Saudi Arabia (as outlined in Table 2.1), although having such a big amount of this type of personnel in healthcare may lead to undesirable repercussions on the quality of care (Albougami, 2015). A considerable number of foreign medical staff are not able to speak the Arabic language, which means communication with patients, and even between staff, can be hard. It is also the case that there is a large cultural gap between staff and patients, because, for example, a lot of Saudi people, particularly elders, have a very traditional culture, and therefore there exists a gap between them and the personnel treating them.

Poor communication between different cultural groups within the healthcare workforce has also been cited as a problem (van Rosse et al., 2016). Furthermore, such a large number of expatriate workers may present a problem in terms of performance levels in the workplace (Abujaber & Katsioloudes, 2015). Overseas personnel generate a disadvantage, because they are in the country for relatively short periods, with an average tenure of 2.3 years. Turnover of foreign medical staff in Saudi Arabia is 37% (Al-Ahmadi, 2014). New physicians usually request particular equipment as part of their contract; therefore, when they leave, unused costly equipment will be left with no one to use it.

Table 2.1 Total physicians, nurses, pharmacists and allied health personnel in MOH by nationality (2012 - 2016). Source: MOH statistical year book, 2017. Modified by author.

YEAR						
2016	**2015**	**2014**	**2013**	**2012**	Nationality	Category
14304	13440	11483	10549	9119	Suadi	Physician
28464	27800	26975	27346	26722	Non- Suadi	
42768	41240	38458	37895	35841	Total	
58274	57358	54785	48495	45875	Suadi	Nurses
42982	38021	37069	35367	37073	Non- Suadi	
101256	95379	91854	83862	82948	Total	
3227	2923	2631	2149	1810	Suadi	Pharmacist
298	261	283	232	344	Non- Suadi	
3525	3184	2914	2381	2154	Total	
53565	51553	49307	45194	41031	Suadi	Allied health personnel
3909	3527	3770	5549	4667	Non- Suadi	
57474	55080	53077	50743	45698	Total	

Albougami (2015) studied implications such as cultural, language and communication barriers, which have the potential to compromise the ability to ensure the quality of care to Saudi Arabian patients, and emphasised that foreign healthcare personnel must be supported by language services and technologies for better communication with patients (Albougami, 2015). Health Information Technology (HIT) has a potential role for overcoming language and cultural issues, and reducing communication failures among healthcare personnel (Manojlovich et al., 2015). In a recent survey, after the implementation of RFID technology 82.6% of Operating Room (OR) nursing staff felt that the RFID system improved communication between surgical teams (Paaske et al., 2017). Researchers have developed a RFID system that detects and prevents patient errors in hospitals. This system can automatically check a patient's identity without any verbal communication. RFID systems can make it easy to detect human errors that might lead to unacceptable adverse events (e.g. wrong patient, wrong site, wrong procedure) (Zhao et al., 2014).

2.2.5 Punctuality of Healthcare Providers

Late physician arrival is another important issue in Saudi Arabia. More than 20% of physicians in Saudi tertiary care hospitals arrive more than an hour late (Clinic Management Department, 2014). Almomani & AlSarheed (2016) observed physicians' arrivals at a Saudi hospital for 8 weeks and reported that the average doctors late arrival reached 49 minutes (Figure 2.10).

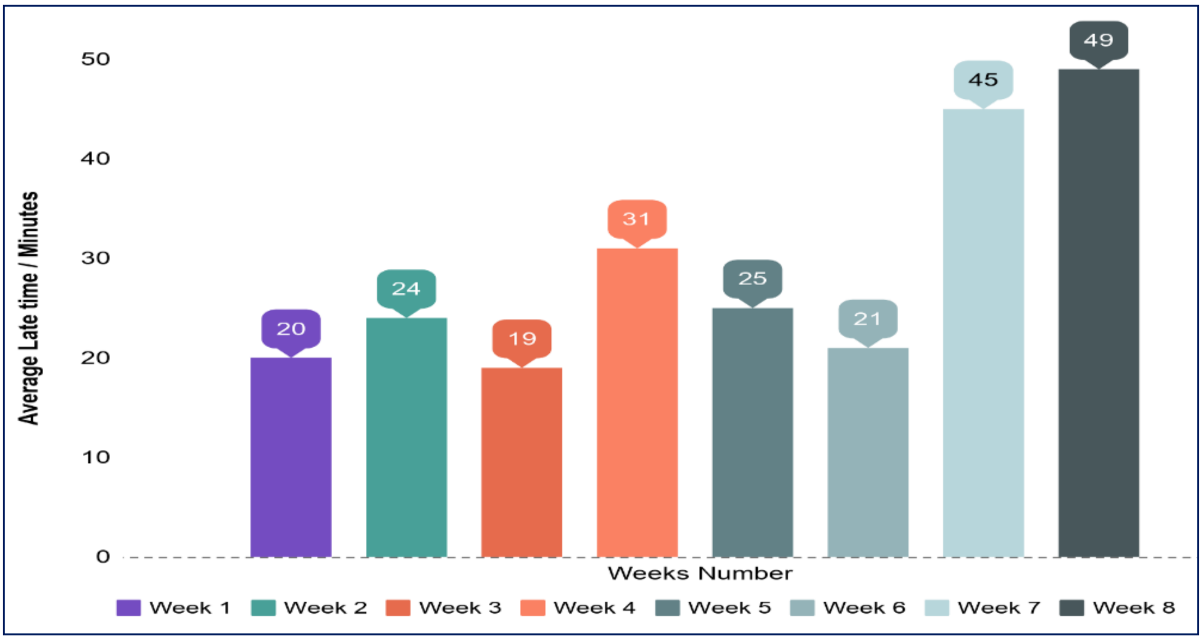


Figure 2.10 Average physicians late time in minutes in Saudi hospital. Source: (Almomani & AlSarheed, 2016)

Doctors' late arrival leads to dissatisfaction of the patients, who wait for a long time after the intial checking by nurses. The impact of ignoring the time attendance by the doctors has resulted in losses to their hospital ranging from $7,200 (SAR26,879) up to $17,558 (SAR65,843) per week (Almomani & AlSarheed, 2016).

In the UK, a recent research looked at data from 2016 and analysed the performance of theatres in 100 NHS hospitals. It found that more than two hours were wasted each day on the average operating list. Furthermore, it has been reported that 280,000 more non-emergency operations a year could be carried out by NHS hospitals if schedules were better organised. The study found that time was lost on avoidable factors, such as surgeons' late starts for operations that had been planned in advance (Baker, 2017). With the implementation of RFID technology in healthcare environment, studies found an increase in physician productivity rates from 43% to 70% (Paaske et al., 2017).

2.2.6 Medical Equipment Availability

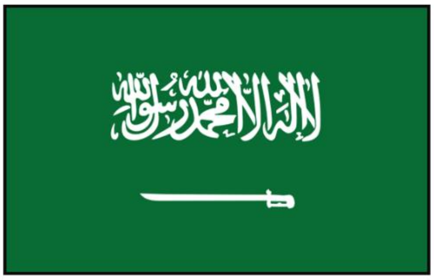
Healthcare systems throughout the world are struggling with the challenge of how to manage healthcare delivery in conditions of resource limitation. The availability and utilisation of various medical equipment, at all levels of the healthcare system, have been emphasised for an effective and efficient service delivery (Ademe et al., 2016). Keeping track and managing medical equipment is a particularly labour-intensive issue in Saudi Arabia, as a large portion of assets is currently lost, stolen or misplaced. Not only are costs increased, but also productivity is affected daily, due to the chaotic nature of hospitals. Reports show that in 2016 stolen medical devices at a Saudi hospital were estimated at £770,000 (Alkhatarsh & Alkadomi, 2016).

In the UK, an investigation reveals that the NHS is losing an estimated £13 million every year from medical equipment thefts (Rossington, 2015). Much time is lost by hospital staff simply searching for medical devices. For example, studies found that nursing staff spends only 25.8% of their time on direct patient care, while the rest of their time is spent on non-direct care activities such as managing stock and equipment (Armstrong et al., 2015). Another study shows that a majority of the healthcare practitioners (85%) spend up to 60 minutes per shift searching for supplies, including wheelchairs and infusion pumps (Ceri et al., 2013).

Time to locate materials and medical equipment, and even other clinical staff, can be greatly reduced by using RFID. This saved time ultimately results in increased time spent with the patient (Paaske et al., 2017). Wamba et al. (2013) stated that technologies such as RFID, ZigBee and Wi-Fi offer an improved method for tracking medical equipment, reducing errors in patient care, facilitating tracing, achieving better management of healthcare assets, and improving the process of audits and the forecasting capacity (Fosso Wamba et al., 2013a).

2.3 Healthcare System in Saudi Arabia

Saudi Arabia is a major entity within the Arab and Muslim world. It is located at the heart of the Arabian Peninsula – see Figure 2.11. Its reputation rests on its standing as the place where Islam was born, as well as being an important producer of petroleum, with 25% of the world's known oil reserves located in Saudi Arabia. The country is the largest petroleum exporter, as well as having a key position in the Organisation of Petroleum Exporting Countries (OPEC).



GDP Total	$1.803 trillion
Population	32 million
Life expectancy	74.8 Years
Area	2.25 million km²
Unemployment	12.1%

Figure 2.11 Saudi Arabia Map, Flag and an overview

2.3.1 Demographics and Economic Patterns of Saudi Arabia

According to recent statistics (Saudi General Authority for Statistics, 2018) Saudi Arabia's population is 32 million – see Figure 2.12. This has grown from 22.6 million in 2010. Prior to that, from 2004 to 2010, annual growth was 2.54%. Saudi citizens comprise 62.9% of the country's population, with 50.2% male and 49.8% female. 65.4% of people are aged between 15 & 64 while 30.3% are under 15 and 4.17% are aged 65+. The UN estimates the country's population will be 39.8 million by 2025 and 54.7 million by 2050.

Location	Saudi Arabia is located in the Middle East, occupying about 80 percent of the Arabian Peninsula.
Surface area	2,25 million Sq. Km.
Length of Coastline	Saudi Arabia has 2,640 kilometers of coastline.
Total population	31.74 million
Pop. Density	14 / Sq.Km
Saudi / Total population %	63 %
Annual Growth Rate	2.54
Crude Birth Rate/1000 Pop.	17.23
Crude Death Rate/ 1000 Pop.	2.9
Total Fertility Rate	2.4
Life Expectancy at birth	74.8

Figure 2.12 Demographic indicators of Saudi Arabia. Source: General Authority for Statistics (2017)

Despite the improvements in Saudi economic patterns, the mortality rate under-5 (per 1,000 live births) is still high compared with other countries such as United States, United Kingdom and Canada, as shown below in Figure 2.13.

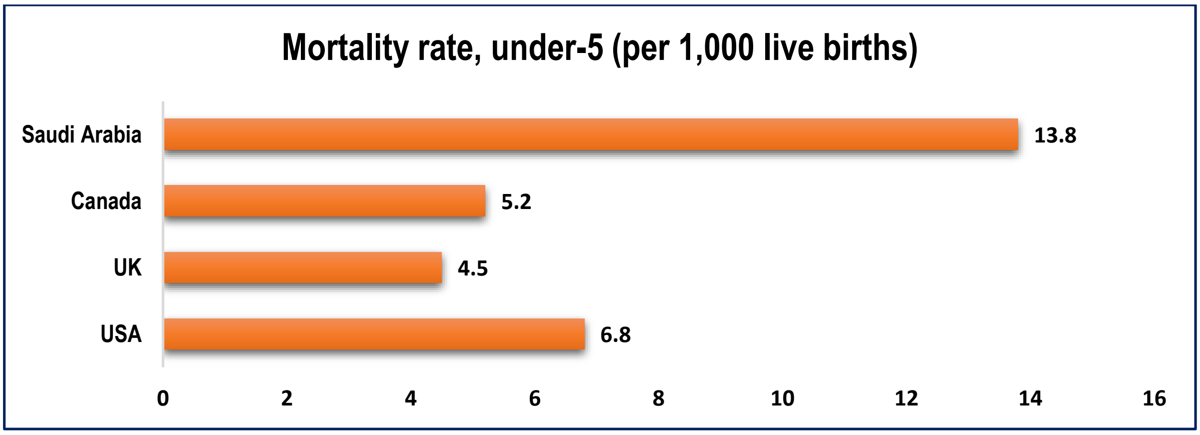


Figure 2.13 Mortality rate, under-5 (per 1,000 live births)

2.3.2 Status of the Healthcare System in Saudi Arabia

The World Health Organization (WHO) defined the main purpose of a healthcare system as *'the people, institutions and resources, arranged together in accordance with established policies, to improve the health of the population they serve, while responding to people's legitimate expectations and protecting them against the cost of ill- health through a variety of activities whose primary intent is to improve health'* (El-Jardali et al., 2014). A healthcare system's multiple components work at different levels as can be seen in Figure 2.14.

Figure 2.14 WHO Health Care System building blocks.

Harding & Taylor (2015) report that the WHO has established a list of essential elements for health systems that function well and answer adequately a population's needs and expectations. These are:

- *Improving the health of people and communities.*
- *Defending the population against health risks.*
- *Protecting people against the financial consequences of ill health.*
- *Providing equitable access to people-centred care.*
- *Making it possible for people to participate in decisions affecting their health and health system.*

Cooper et al., (2016) described the objectives of health systems as reported in WHO reports: the healthcare system aims as improving health, including equality in how health is maintained in a population, being responsive and fair, and maximising use of resources (Cooper et al., 2016). Healthcare systems are made up of a group of connected elements that must work together in order to operate well. Figure 2.15 outlines the healthcare system's functions, as well as crucial correlations between them – see. These functions include:

- *Service delivery, including, for instance, delivery models, infrastructure and quality.*
- *Health personnel, which refers to national employer and employee policies, standards and data.*
- *Information, which includes both facility- and population-based data as well as worldwide standards and tools.*
- *Medical products, vaccines, and technologies, which includes the guidelines and policies attached to these, as well as dependable supply, fair access and quality.*
- *Financing, such as national policies, statistics and prices.*
- *Leadership and governance, including policies, consistence and management* (Morton et al., 2016).

These roles are carried out with the ultimate objective of attaining three aims: community health, responsiveness, and funding that is equitably distributed (WHO, 2014). Most of these aspects can be provided and enhanced by digital healthcare infrastructures.

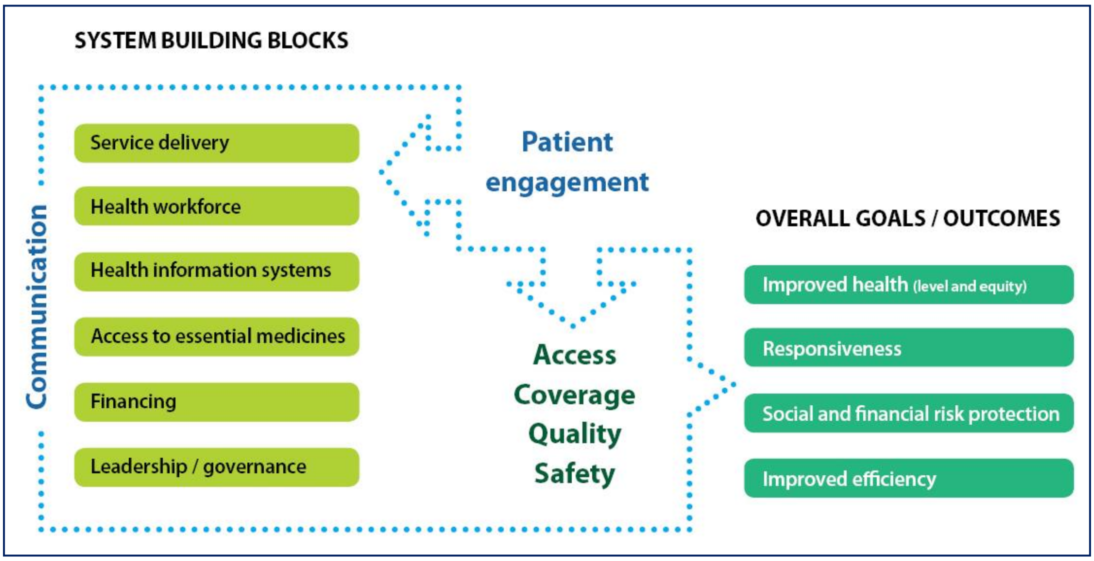


Figure 2.15 WHO healthcare system aims and objectives. Source: http://www.healthsystemsglobal.org

Saudi Arabia aims to have a universal healthcare, available to all those residing in the country. The government provides, at the present time, 80% of hospital services, managing them through its various agencies. The private sector provides the remaining 20% of healthcare services. The largest provider within the governmental bodies is the Ministry of Health (MOH), accounting for the administration of around 62% of the services. MOH dispenses services dealing with prevention, cure and rehabilitation. A further 38% of services are facilitated by over ten government agencies, which incorporate the Ministry of Defence and Aviation, National Guard, Ministry of the Interior, and hospitals run by universities. These dispense primary, secondary and tertiary healthcare. The MOH is presently the central government healthcare source and financer in Saudi Arabia, dispensing as a matter of policy free care for citizens of the country. The concept is to provide every Saudi citizen with access to healthcare, with a goal of non-profit services being available in public facilities. The MOH has three healthcare levels, Primary Care Centres, Secondary Care Hospitals and Tertiary Care Hospitals; it runs currently 2337 facilities, including 2037 primary care centres, which exist around the country. There are 244 secondary care hospitals located in cities alongside 56 tertiary hospitals in the largest cities of the Kingdom, as shown in **Error! Reference source ot found.**.

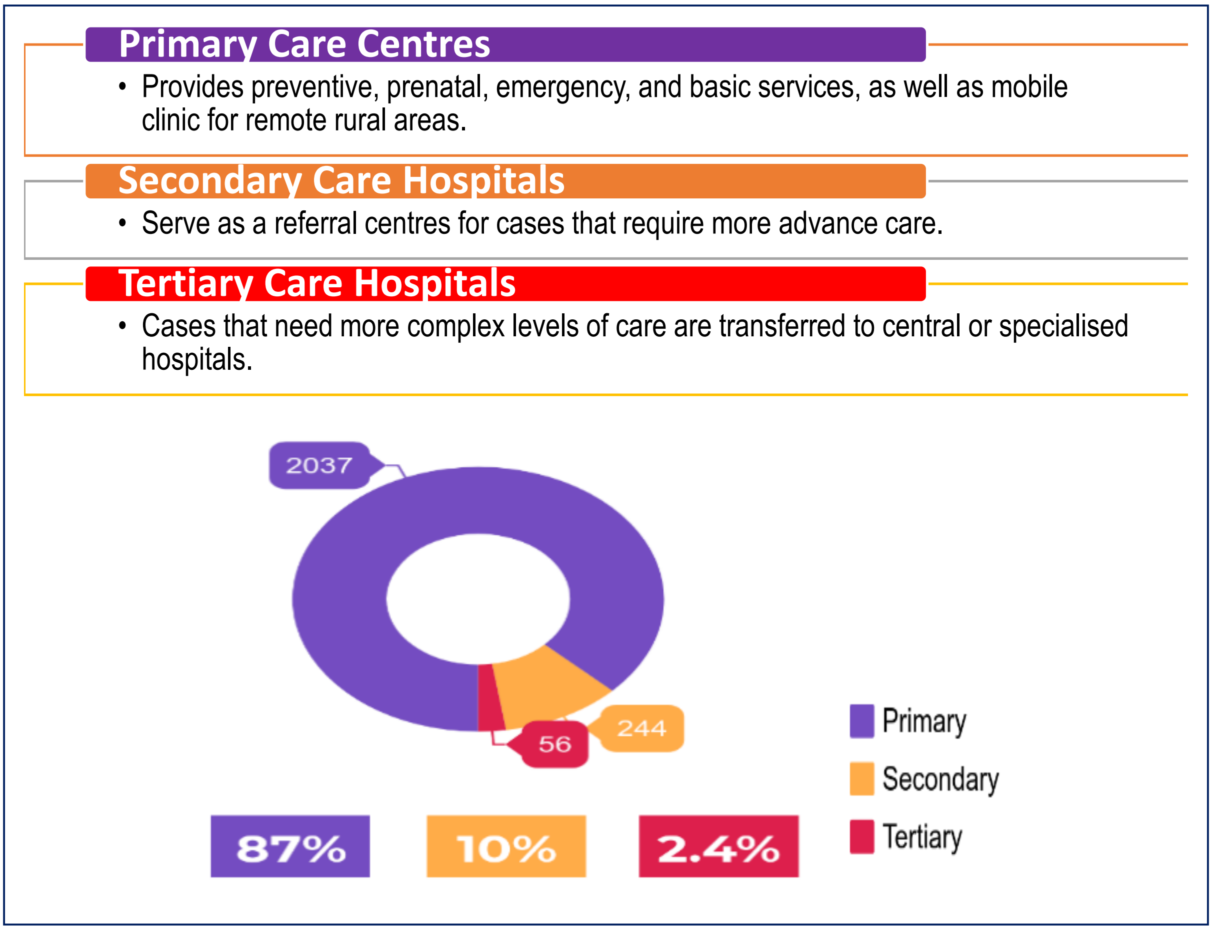


Figure 2.16 Healthcare Levels in Ministry of Health (Saudi Arabia)

Healthcare facilities and hospitals supply outpatient services. Patients receive care in different facilities according to the health condition being dealt with. Patients will attend primary care centres when they are stable, or will be referred to a secondary or a tertiary hospital when they are not so. Additional government organisations dispensing healthcare are incorporated referral hospitals, such as: King Faisal Specialist Hospital and Research Centre, Security and Armed forces’ hospitals, Aramco hospitals, Educational institutions teaching hospitals, the Red Crescent Society, School health units coming under the Ministry of Education, as well as the Royal Commission for Jubail and Yanbu healthcare services. Beside the teaching and referral hospitals and the Red Crescent Society, the above bodies serve specific groups of people, most often their employees. They also contribute to the healthcare system in the whole country if a crisis or emergency occurs. Together these bodies manage 39 facilities with 11,043 beds as their combined capacity. Another contribution to the delivery of healthcare comes via the private sector. This is particularly the case in large towns and cities, which have 137 privately owned hospitals, comprising 14,165 beds – see Figure 2.17. In 2016, there were 476 hospitals in Saudi in total, representing an addition of 8 new hospitals since 2015.

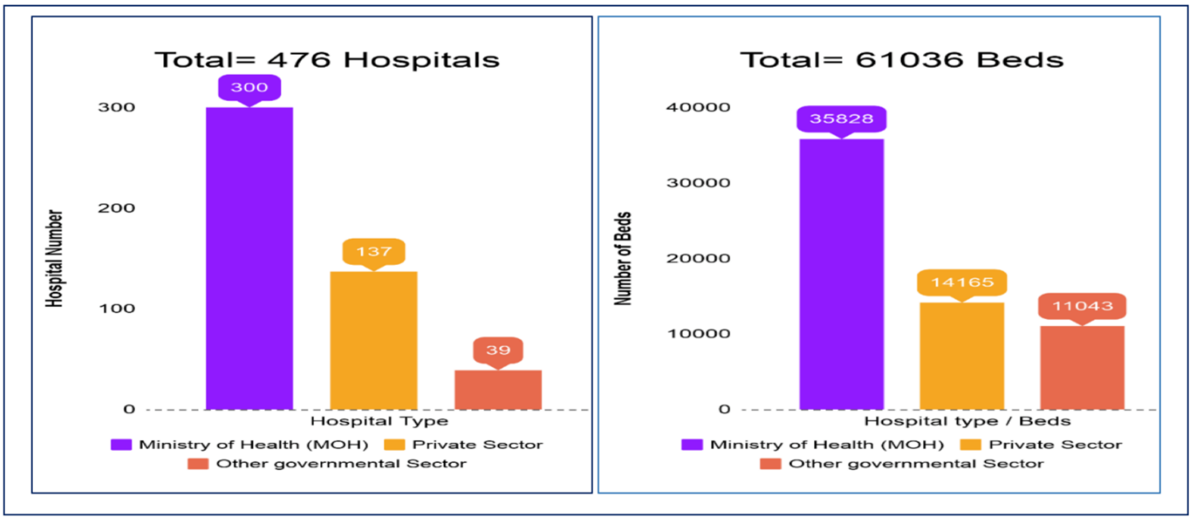


Figure 2.17 Number of Hospitals & Beds in Saudi Arabia

The number of beds totalled 61,036 in 2016, a 2.09% increase since 2015. Bed numbers in Ministry of Health facilities were 35,828, which represent 59.1% of all beds in the country. Bed rate per 10,000 people living in Saudi Arabia was 20.9 in 2016, which translates as one bed to every 448 people. In 2016, the grand total number of patients' visits to health centres, private general and specialised polyclinics, and hospitals in all health sectors, was nearly 138 million visits. The annual average number of visits to health facilities in all health sectors was 4.4 visits for each person of the KSA population (Ministry of Health, 2017).

Healthcare progress has been shown by relevant health indicators, in terms of services offered alongside additional elements, including quality, attainable education, community awareness surrounding health and life conditions. However, the healthcare system in the KSA has been ranked as 45th in a recent international report that examines healthcare systems performance in 149 countries. The Legatum Prosperity Index measures a country's performance in three areas: basic physical and mental health, health infrastructure, and preventative care (Mousavizadeh et al., 2016). Notably, there is a lack of coordination and appropriate communication among the healthcare providers, which translates into doubling and wasting of efforts, and waste of valuable resources. There is a significant opportunity, for example, to develop the health infrastructure and to make better use of equipment, training resources, and medical staff by using digital systems and by activating e-Health solutions properly (Ventola, 2014).

A comparison with the healthcare situation in developed countries is provided by a recent study of seven countries, which designated the UK's healthcare system as one of the world's most efficient, setting it up as a positive example to follow (Schneider, 2017). According to the Commonwealth Fund report, the UK ranked first in terms of overall performance, with the metrics including quality, efficiency, access, equity, and healthy lives. The UK performed very well in care process and equity, and ranked third in access. The UK also ranked third in efficiency, which was measured by examining total national spending on healthcare as a percentage of GDP, as well as the amount spent on healthcare administration and insurance. Regarding healthcare access, the study states that the UK has shorter waiting times for basic and non-emergency services after hours, but longer waiting times for specialist care and elective, non-emergency surgery (Schneider, 2017). In general, the UK achieves superior performance compared to other countries in all areas, except healthcare outcomes, where it ranks 10th – see Table 2.2.

Table 2.2 Health Care System Performance Rankings for Seven Industrialised Countries. Source: Commonwealth Fund analysis (2017)

	UK	AUS	NETH	NZ	NOR	SWE	SWIZ	GER	CAN	FRA	US
OVERALL RANKING	**1**	**2**	**3**	**4**	**4**	**6**	**6**	**8**	**9**	**10**	**11**
Care Process	1	2	4	3	10	11	7	8	6	9	5
Access	3	4	1	7	5	6	8	2	10	9	11
Administrative Efficiency	3	1	9	2	4	5	8	6	6	11	10
Equity	1	7	2	8	5	3	4	6	9	10	11
Health Care Outcomes	10	1	6	7	3	2	4	8	9	5	11

2.1.3 Status of e-Health in Saudi Arabia

Information and Communication Technologies, ICT, are engaged in progressively imparting the knowhow and tools necessary for improving healthcare. This, in turn, facilitates finding answers to questions on how best to advance patient welfare and generate an improved level of skilled personnel and better institutions, in both private and public fields.

E-Health can be a means to achieve better conditions for healthcare in the developing world, especially for populations in rural or remote regions. The World Health Assembly in 2005 identified e-Health as a means to bring about cost-efficient and safe usage of ICTs in the area of healthcare. The Assembly proposed that member nations should evaluate whether longer-term strategic plans could be made for evolving and putting into effect e-Health services and infrastructure as a standard part of all countries' healthcare. Almuayqil et al. (2015), described e-Health as digital data usage, where such data is transmitted and stored electronically in the health sector in support of care, either at a local site or at a distance (Almuayqil et al., 2015). The WHO, defined e-Health as '*the use of information and communication technologies (ICT) for health. The e-Health unit works with partners at the global, regional and country level to promote and strengthen the use of ICT in health development, from applications in the field to global governance*' (Ariani et al., 2017). Figure 2.18 outlines some of e-Health advantages.

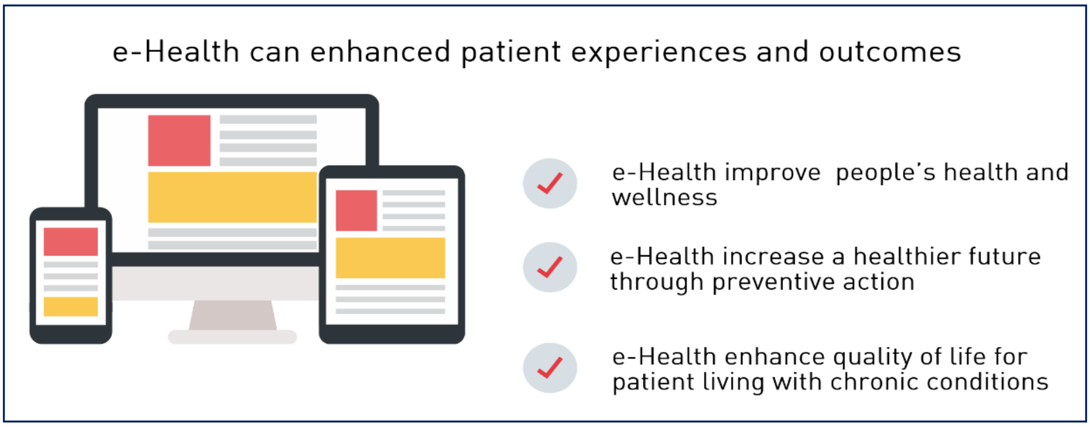


Figure 2.18 e-Health advantages

There are endless potential applications for e-Health, as a result of the substantial pervasiveness of information and communication technologies (ICT). General uses incorporate the following aspects:

- Telemedicine and tele-Health systems, which transmit medical information for diagnostic relay and diagnosis guidance – Those are known to save money, expand access, and promote best utilisation of digital health resources.
- Electronic Health Records (EHR) and Electronic Medical Records (EMR), incorporating records of patient, electronic booking and electronic prescribing, clinical admin, and archiving.
- Consumer informatics applications, which include many health-oriented websites and lots more smartphone apps that are increasingly in demand.

- Consumer wearables, which can provide patients with personalised health data and could assist with self-diagnosis and behaviour change interventions – See Figure 2.19 (Piwek et al., 2016).
- IT systems, such as medical imaging, radiology, computer-aided diagnosis, surgery, training and planning, and systems used by nursing. All these help medical staff to dispense treatment that is more precise.
- More connected networks - regional, national, and international - that enable location of services in rural and remote locations.
- E-Health technology within IT systems, for use in, for example, clinical management, organisation of supply chains, billing, scheduling, as well as other means of supporting decision-making.
- Online IT systems, including, for example, health portals, which are utilised extensively for dispersing information in order to advocate for healthy patient and consumer behaviour.
- E-Health systems used in research, for example: development of pharmaceuticals, analysis of public health data, outcomes' analysis, and infectious disease biostatical programmes.

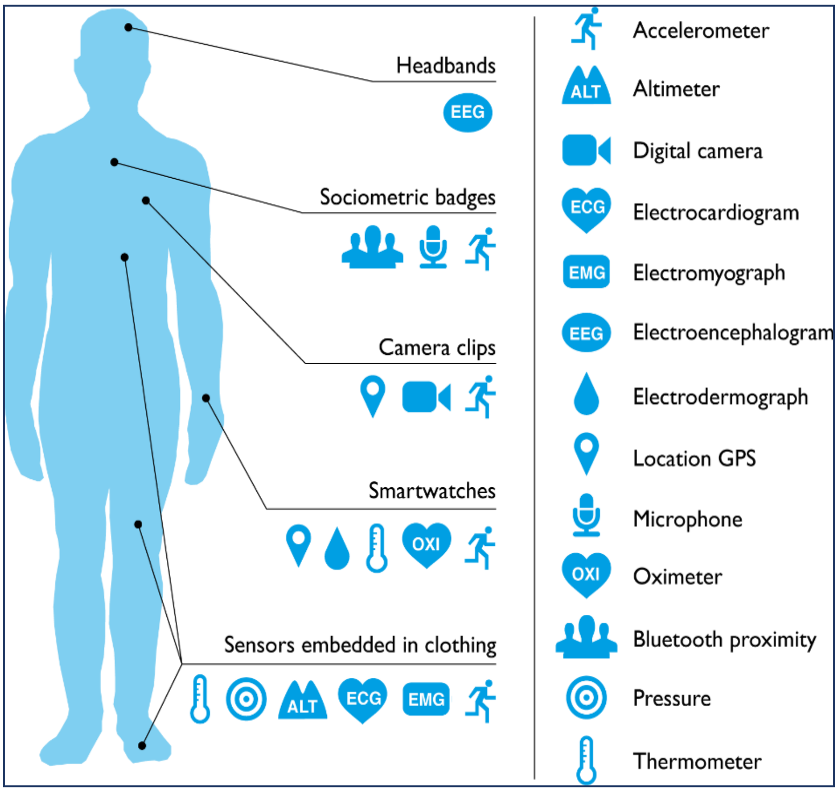


Figure 2.19 Consumer Wearables with Personalised Health Applications. Source :(Piwek et al., 2016)

Various e-Health technologies were analysed by Koivumaki et al. (2017) to assess these solutions in terms of quality and safety, and to help inform professionals on future e-Health applications. Table 2.3 shows each technology's effectiveness, with examples. E-Health improves the patient experience and general healthcare systems development as well.

Table 2.3 e-Health solutions & Improvements (Koivumaki et al.,2017)

e-Health can	***To improve***	***Example***
Connect healthcare providers & patients with valuable sources of data and information	Diagnostic accuracy; treatment appropriateness; accountability of care	e-Records, Gene Banks, e-Diagnosis, e-Decision Support
Include citizen-informed, culturally sensitive, population-specific design & content	Access to healthcare across social, geographical or cultural contexts	e-community, Telemedicine, Remote technologies
Provide analytical and predictive modelling using data integrated across systems.	Evidence-informed preventive action at the individual, system & population levels	Surveillance platforms, e-detection, e-Health map
Enable access to personal health information & support care providers	Citizen empowerment in health maintenance & autonomy at home and at work	Smart wear /clothing

However, there are concerns within Saudi Arabia that e-Health and ICT are not being utilised appropriately, to the extent they could be (Chikhaoui et al., 2017; Alaboudi et al., 2016; Uluc, 2016). Utilising these technologies has begun in some hospitals, but currently the uptake is not progressing quickly in the Ministry of Health facilities. Some information systems are running in regional bodies as well as in central hospitals. Unfortunately, these systems are not linked with one another or to any other medical organisations. In order to advance the e-Health services in public sector, $1.1 billion (SAR 4 billion) from the Ministry of Health was assigned for development projects. The volume of e-Health research accessible in the country is limited. Some research exists, focussing on the application of e-Health such as data mining, dental informatics and Electronic Laboratory Information Exchange (ELIE). These show that some organisations are aware of e-Health and have implemented it, but that there are various challenges that healthcare organisations need to address. A Research by Almaiman et al., (2013) was carried out to review e-Health used by the Primary Healthcare Centres (PHCC) in Saudi Arabia. Collecting data comprised conducting interviews with 15 stakeholders, alongside searching for keywords in academic sources. It was discovered that although there were developments in e-Health, including online appointment booking services and file updating in primary healthcare centres, there remain many challenges to address. For example, the persistence of paper medical records, and discrepancies in the way health information technology is being distributed and managed. Other research considered the uptake of Electronic Health Record (EHR) and Electronic Medical Record (EMR) in the country, and shows that although take-up is increasing, the systems being put into effect involve challenges that are slowing down implementation. Studies found evidence that uptake of EHR is increasing, and some bodies implementing it are considered successful in the context of the Middle East. Bah et al (2011) studied 19 hospitals, to discover the uptake and expanse of e-Health services and applications being utilised in Saudi government hospitals. With the aid of a questionnaire, IT managers' thoughts on e-Health in these particular hospitals were gathered. The results showed that just 3 hospitals made use of EHR. The central issue was opposition from physicians and nurses. The latter had unfavourable views towards e-Health, with concerns about confidentiality and security, a lack of motivation to learn new technologies, and lack of adequate training. Rowibah et al (2012) conducted a further study in which questionnaires were given out to physicians within a number of hospitals. This research was carried out in Riyadh at King Fahd Medical City and 93 physicians took part. The results confirmed that computerised physician order entry (CPOE) improved effectiveness, but the researchers' state that CPOE does not give adequate guidance for users, and could lead to mistakes being made.

Furthermore, a succession of e-Health conferences, which are held frequently in Saudi Arabia, raised the awareness of e-Health importance. The aim of these conferences was to highlight e-Health's value in improving healthcare delivery, and to consider infrastructure, strategies and policies that are requisite for implementation. In order to build on e-Health usage and institute a comprehensive countrywide health information system, greater coordination amongst healthcare providers is necessary. In order to produce a sustainable infrastructure, coordination also needs to be realised with other sectors, including ICT services providers.

It is useful to compare the KSA e-Health status with that in countries such as the UK, where a National Advisory Group on Health Information Technology in the UK was formed in 2015 to advise the Department of Health and the NHS on digitalising the secondary care system (Wachter, 2016). Most patient records are now computerised in GPs, and some practices allow patients to make appointments online or to email their GP. New legislation requires primary, urgent, and emergency care services to become paperless by 2019, and for the NHS by 2020. The Advisory Group advocates digitisation in stages, with trusts that are lagging being supported to build this capacity over a span of several years. Phase 1 (2016-2019) intends to combine national funding with local resources, to support trusts that are ready to digitise, while improving the digital maturity of those trusts that are already digitised. If the 2020 deadline is not met, a second stage, Phase 2 (2020-2023) will provide more government funding (Wachter, 2016). The online portal NHS Choices will act as single point of patient access for registration with a GP, appointment booking and prescription ordering, digital tools access, communication vehicle with the patient's doctor, and for access to the patient's full health record (Department of Health, 2014). The goal is complete electronic medical record access for patients by 2019, with the extension by 2020 to cover all health and healthcare interactions. GPs commonly send prescriptions to pharmacies electronically and store and distribute digital images (i.e., X-rays, scans) electronically as well (NHS England, 2014). A pilot of this program began in 2014 in 265 general practices, but full implementation is not yet ready.

2.4 Saudi Arabia Vision 2030

The Kingdom of Saudi Arabia (KSA) is known as one of the main oil producers. Since this is not a sustainable resource, the government developed a wide-ranging program that would consciously shift the entire country's revenue streams to more reliable products and services. The program employs many enablers to aid in the adjustment of various processes, some of which are transparency, institutionalisation, and specialised support (NTP, 2016). The ultimate goals of the program are to reduce the country's reliance on petroleum revenues (as statistics show a decrees in oil revenue in the last 5 years (see Figure 2.20)) and to become more resilient to petroleum price fluctuations through a stronger economy (Bhatia & Group Economist, 2016; Kinninmont, 2017).

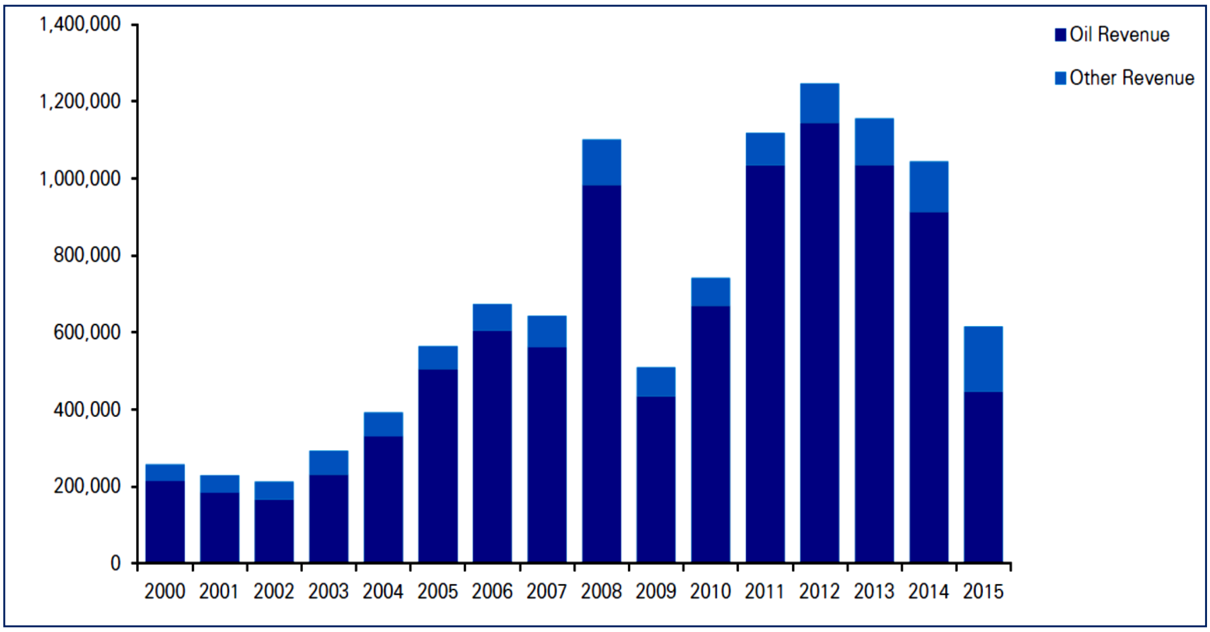


Figure 2.20 Oil revenue as a ratio of total revenue, 2000-2015 in Saudi Riyals. Source: Saudi Arabian Monetary Agency, Annual Statistics (2016)

This section will discuss the program, called "Saudi Arabia Vision 2030" (Vision 2030), and illustrate its expected impact and relevance on the healthcare sector in the KSA over the coming years.

2.4.1 Overview of Saudi Arabia's Vision 2030

The Vision 2030 is an "ambitious yet achievable blueprint" for Saudi Arabia to leverage its existing strengths and to expand its capabilities. The Vision is driven by the KSA values, with a focus on moderation, tolerance, excellence, discipline, equity and transparency. (Government of Saudi Arabia, 2016). There are multiple phases (as seen below in Figure 2.21) being carried out to implement the Vision, and the first phase has already begun.

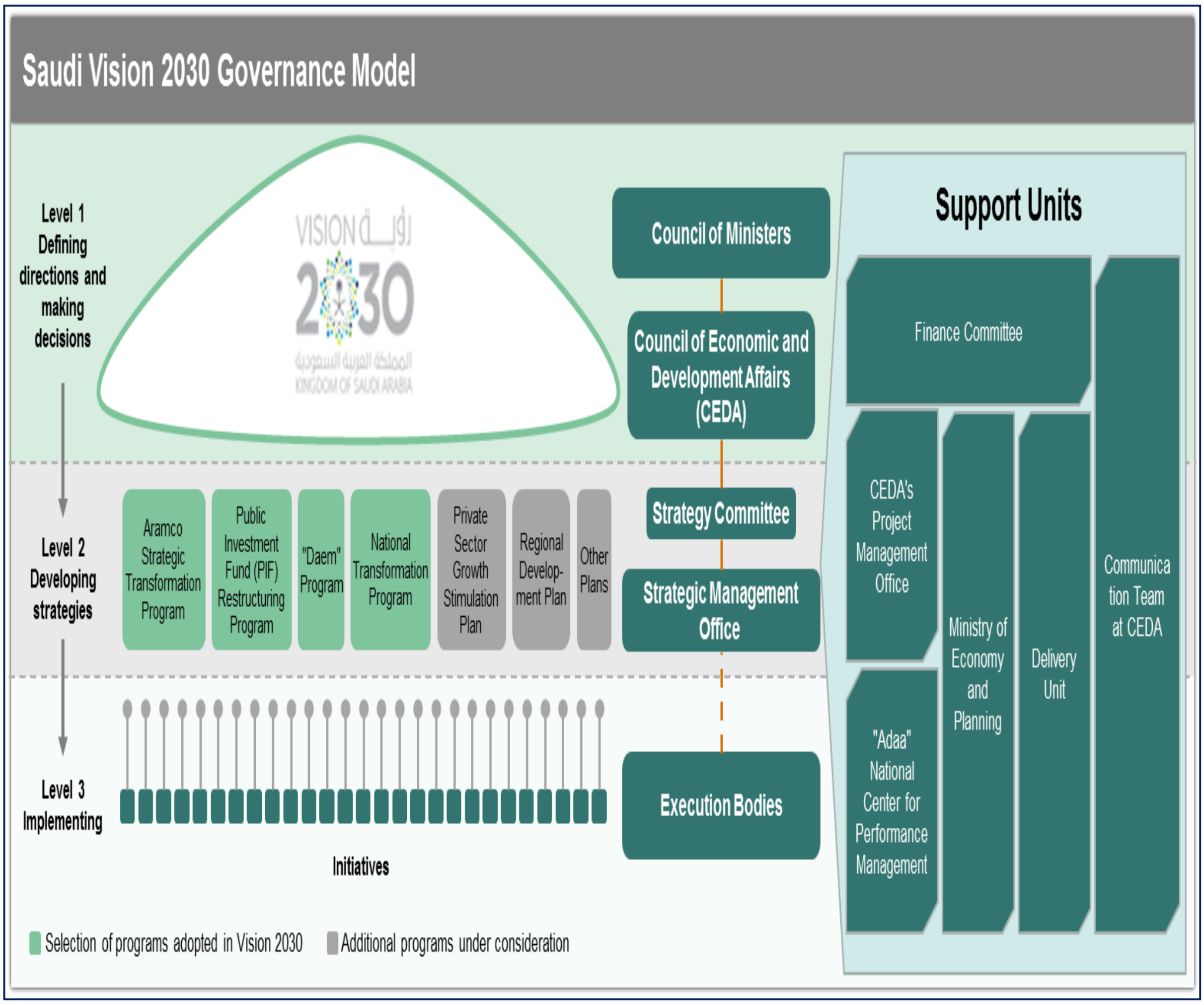


Figure 2.21 Governance Model for Achieving Saudi Arabia's Vision 2030. Source: www. http://vision2030.gov.sa

In April 2016, Saudi Arabia unveiled the highly anticipated details of the National Transformation Program 2020 (NTP), which outlined the country's five-year plan in regard to its strategic objectives, and identified the challenges in achieving Vision 2030. The NTP therefore provides the systems for building the institutional capacity to fulfil the goals of Vision 2030, by addressing every relevant aspect of the public sector – see Figure 2.22 (National Transformation Program, 2016). The NTP includes 543 approved initiatives costing an estimated US$70 billion (SR270 billion); and establishes 178 strategic objectives, 350 performance targets and 400 benchmark indicators to guide 24 government bodies through the end of 2020.

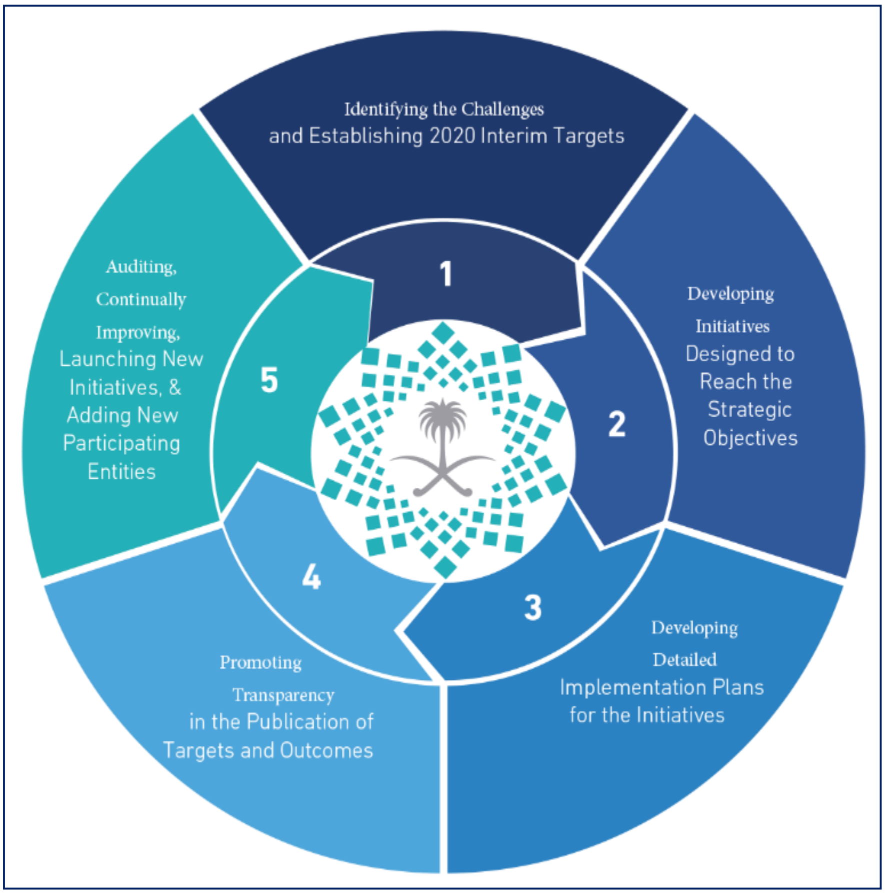


Figure 2.22 Operating Model of the National Transformation Program (NTP)

2.4.2 Impact of Saudi Arabia's Vision 2030 on the Healthcare Sector

The 178 strategic objectives outlined by Saudi Arabia's Vision 2030 target all ministries. Those most relevant to health aspects are the Ministries of: Finance; Economy and Planning; Health; Communications and Information Technology; Commerce and Investment; and Environment, Water, and Agriculture.

The Ministries of Finance and of Economy and Planning manage the development of Saudi Arabia's long-term economic future, and therefore affect how the healthcare industry is financed, for example through privatisation that should help to reduce bureaucracy (Madureira, 2015). The Ministry of Health is directly responsible for the utilisation of the government's funding, to ensure that the objectives are met in regard to primary health providers, health research, health insurance, improvement of current practice and performance (NTP, 2016). Communications and Information Technology are vital for these purposes and, as our research discusses, more utilisation and better performance are needed for healthcare personnel and assets, which can only be achieved by means of developing tracking and monitoring technologies. Commerce and Investment are relevant, since Saudi Arabia is only recently opening up its field of investors internationally This action will benefit the country in the long run, by promoting greater investment in its people and its resources, so that healthcare will ultimately gain more funding. The Ministry of Environment, Water, and Agriculture is important for its role in deciding on the industrial impact on the KSA's citizens' health. By its combined elements, the Vision 2030 will impact on every aspect of life, so it is vital that each aspect supports the objectives aimed at improving the Ministry of Health – see Figure 2.23.

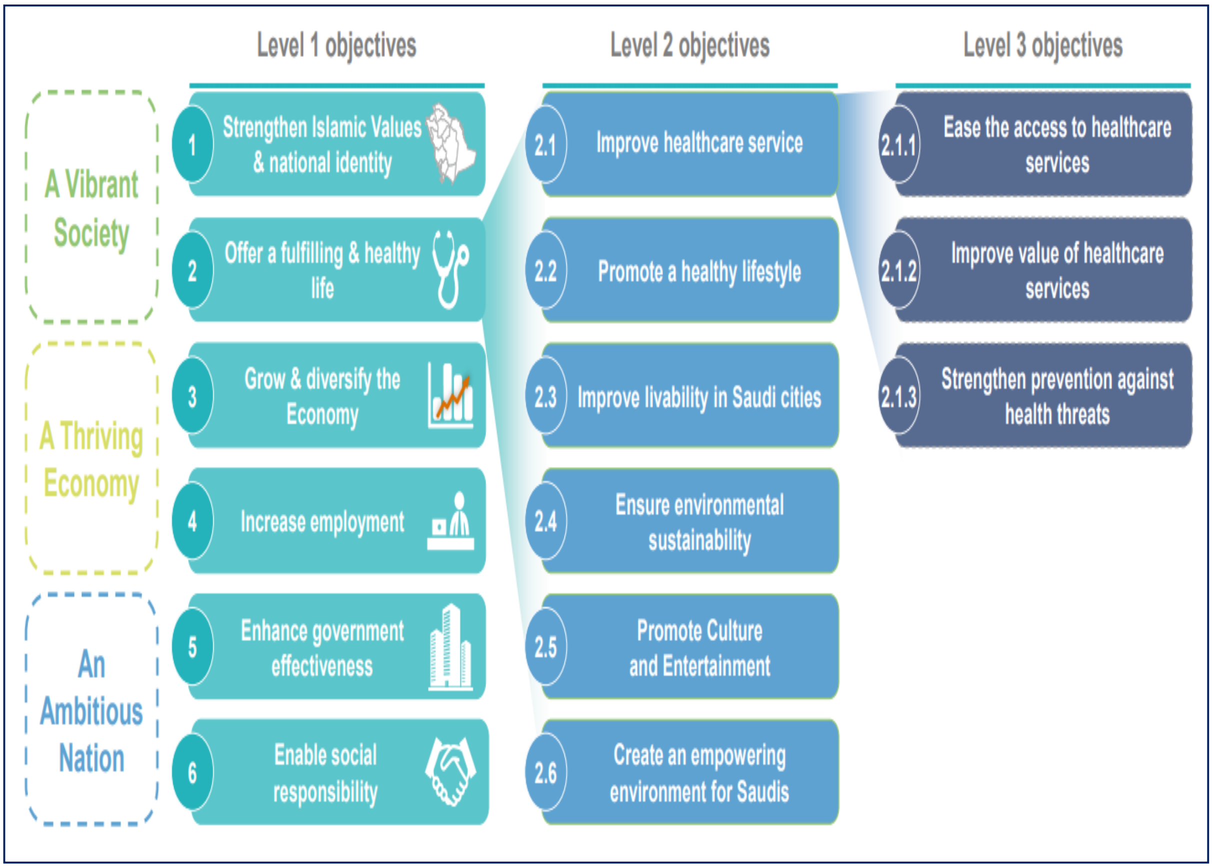


Figure 2.23 Healthcare Strategic Objectives in Saudi Vision 2030.

Healthcare is targeted by an increase in the private healthcare expenditure from 25% to 35% and by an increase of the total revenue generated by the private sector from $80 million (SR300 million) to $1.06 billion (SR4 billion). This plan allocates $6.1 billion (SR23 billion) (nearly 10% of the entire budget of the NTP) for the MOH to spend over the duration of the program on new initiatives, such as reforming and restructuring the health sector and the establishment of private-public partnerships (Bhatia, 2016; Kinninmont, 2017). Of the 178 strategic objectives of the NTP, 15 are devoted to healthcare, allocating a specific budget of $6.1 billion

(SR23 billion) to each objective (NTP, 2016). Some of the most prominent healthcare objectives, (which emphasise the objectives of our research) include:

- *Increase the efficient utilisation of available resources*
- *Improve the efficiency and effectiveness of the healthcare sector through the use of information technology and digital transformation*
- *Improve the infrastructure, facility management, and safety standards in healthcare facilities*
- *Attain acceptable waiting times across all stages of service delivery*
- *Improve governance in the health system in order to enhance accountability with regards to quality issues and patient safety*
- *Improve quality and safety principles as well as skills of service providers*

Although, the expansion of the Ministry of Health aims to develop hospitals, which is one of the focuses of our research, improving people's general health through active lifestyles and the environmental impact of cities will also alleviate much of the burden placed on hospitals in terms of preventable diseases.

Most encompassing of the Vision 2030 is the aim to develop '*a society in which all enjoy a good quality of life, a healthy lifestyle and an attractive living environment*' (Saudi Vision 2030, 2016). It is important to note that one of the three primary aims in Saudi Vision 2030 is on health, achieved not only through the promotion of physical activity, but also through the improvement of the healthcare sector. It is clear that by 2030, Saudi Arabia intends to achieve much greater control over its healthcare sector.

2.5 Conclusion

In this chapter, challenges confronting healthcare and e-Health in Saudi Arabia, such as patient misidentification, waiting time, performance, efficiency and late doctor's arrival were addressed. Our research pointed out that greater use of electronic devices and technologies would contribute greatly to meeting these challenges. Major difficulties were seen to arise from the high percentage of short-term foreign personnel in the healthcare field, including language barriers, both between staff and patients and amongst medical personnel.

However, our research concluded that these ground level difficulties must be considered in the larger strategic, national context, which shows an extraordinarily large population increase from 2010 to 2018, with an even greater, and still growing, increase in the aged population. The government is facing this challenge with its Vision 2030 plan, which envisages deep, radical changes in almost every aspect of the economy and of the social structures of the country. Healthcare has a central position in this Vision, and our research concluded that the accelerated introduction, acceptance and implementation of electronic technologies and e-Health throughout the Healthcare system are not only highly beneficial in their own right (as shown by many examples given in this chapter) but are also essential for coping with the surge of health demands, which cannot be met by just the supply of largely foreign, short tenure medical professionals. It is clear that the available human elements must be empowered to achieve higher productivity by complementing their efforts with the best modern technologies and up-to-date systems available. Our conclusion is that the modernisation of the healthcare structures needs to be a central element in the implementation of Vision 2030.

Chapter 3 Using Technology to Tracking & Monitoring Patients, Assets and Staff

3.1 Introduction

This chapter provides detailed information on using technology to track and monitor people and assets within the healthcare environment. The aim is to propose and develop a novel Smart e-Health model for tracking and monitoring purposes. The relevant literature incorporates global information, but it was reviewed with the intention of applying the results to Saudi Arabia, and this chapter focuses on Radio Frequency Identification (RFID) and ZigBee technologies. This research investigates solutions to issues such as reducing costs and improving performances and efficiencies in Saudi Arabian hospitals.

This Chapter is organised as follows:

- Definitions of tracking technologies and of most popular performance metrics.
- Introduction of Real-Time Location Systems (RTLS).
- Descriptions of indoor locating and RTLS technologies and of their detection methods.
- Smart hospitals and recent developments in healthcare facilities and in the use of RTLS technologies, to improve workflow and optimisation for both people and assets.
- Comparison of real-time tracking technologies, using factors such as accuracy, coverage, frequency, applications, and advantages and disadvantages,
- RFID overview, including RFID system components and RFID applications in healthcare.
- ZigBee overview, including ZigBee system components and ZigBee applications in healthcare.

3.2 Indoor Locating and Real-Time Tracking Technologies

Initiatives for enhancing the individuals' quality of life have been gaining increasing importance in the agendas of policy makers. Smart City is one of these initiatives. Smart cities are cities built applying 'Smart' and 'Intelligent' solutions and technologies that will lead to the adoption of at least five of the eight following Smart parameters: Smart energy, Smart building, Smart mobility, Smart healthcare, Smart infrastructure, Smart technology, Smart governance and education, and Smart citizen, as shown in Figure 3.1. Smart healthcare is the use of e-Health systems and intelligent and connected medical devices. It also involves the implementation of policies that encourage health and well-being for its citizens, in addition to health monitoring and diagnostics, as opposed to medical treatment. Indoor and outdoor tracking, monitoring and locating technologies are the most useful tools to help achieving these purposes (Aziz et al., 2016).

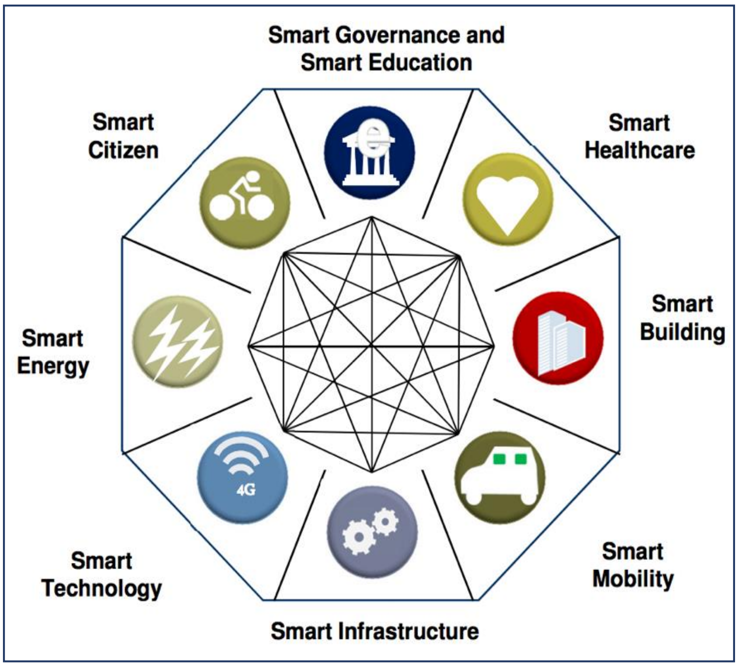


Figure 3.1 Smart City Concepts. Source: Aziz et al., 2016

Indoors locating technologies are positioning systems developed for automation applications through automatic object location detection.

These locating technologies go by many names, including geolocation, location sensing, and position location. Some applications of location detection include product location in a warehouse, navigation, and locating medical devices or personnel in a hospital (Chen et al., 2014a). Asset tracking and inventory management are some of the most popular uses for positioning systems, and this is a growing industry with widespread applications, particularity in the last 20 years (Khudhair et al., 2016). Demand for wireless systems has entered the consumer applications market, with the proliferation of wireless technologies and information, especially with location-based services (LBS) and telecommunication networks. In the United States, LBS formally goes back to 1996, when the government passed the Enhanced 911 mandate, which was used for locating emergency callers with accuracy; this was before 3G networks were introduced in 2000 (Yassin et al., 2017). LBS depends on user location, and determines the motion activity of the mobile user, which means that the LBS requires locating technologies and must deliver an enormous number of personalised services, as shown in Figure 3.2. LBS employs software, a communication network, a content provider, a positioning device, and the user's active device (Farid et al., 2013).

Figure 3.2 Location-based services (LBS) Source: www.rishabhsoft.com (2018)

The most popular use for outdoor positioning systems is the global positioning system (GPS), as satellites have access to mobile users when they are above ground and have an unobstructed view of the skies. Indoor positioning systems, however, utilise technologies that can pass through obstacles such as walls, and which can provide higher accuracy than GPS, since room or object location must be precise. Therefore, indoor positioning requires more complexity and is dependent on the specific operating environment. Some factors determining the complexity include the dimensions of the environment, high non-line of sight (NLOS), physical obstacles, interference from other equipment in the proximity, and moving people (Liu et al., 2017). Signal property characteristics include their strength patterns and the ability of electromagnetic waves to propagate as desired. Due to the increased dimensions involved in developing a reliable indoor positioning system, performance metrics are implemented to ensure high standards. These metrics usually include accuracy, responsiveness, coverage, adaptability, scalability, security, cost, and complexity. Accuracy is the reported difference between estimated location and actual location. The greater the accuracy of a system, the more reliable the system is. Responsiveness measures the time delay for an updated location estimate of the target. Coverage is classified as local, scalable, and global. Local coverage is a limited and non-extendable area, typically a room or building. Scalable coverage is extendable through additional hardware, and global coverage refers to worldwide system performance. Adaptability is the ability of the system to manage environmental changes; similar to this is robustness, which is the ability to function normally when some signals become unavailable. Scalability measures the system performance when operating with more location requests and larger coverage than normal. Security of positioning data is important within a private or personal network. Cost of a positioning system includes infrastructure, bandwidth, energy, and installation. Complexity of algorithms and processing is traded off with accuracy and cost, and is therefore a factor that must be balanced with cost (Zafari et al., 2017).

A key component of responsiveness is the ability of a location system to function in real time. Real-time location systems (RTLS) are technologies that *'automatically identify and track the location of objects or people in real time, typically employed through wireless tags worn by people'* (Newswire, 2015). Fixed points receive the signals from the tags to keep constant reference of their locations as seen in Figure 3.3.

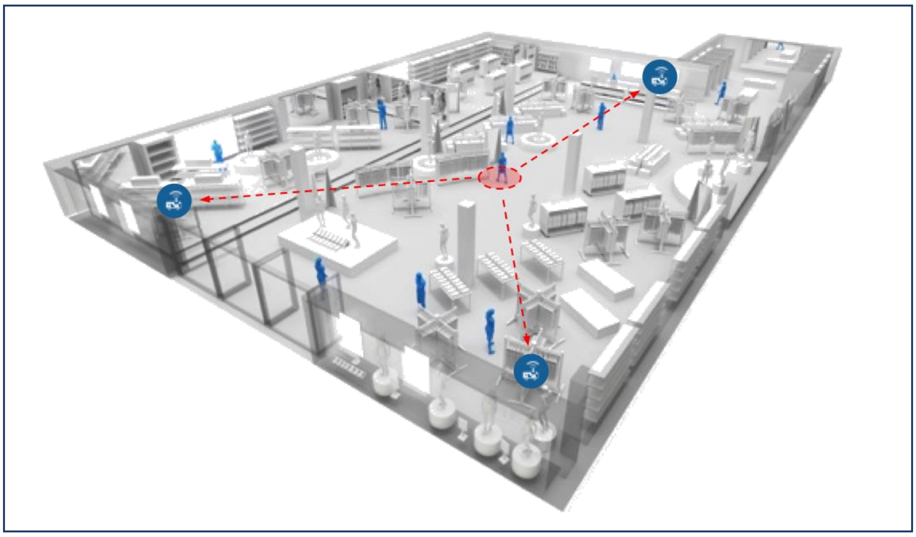


Figure 3.3 Real-time location systems. Source: http://www.walkbase.com (2018)

Besides being more efficient than outdated manual system, RTLS generate more intelligence by providing data about the movement of every tag within a facility. This intelligence can be used by hospitals to improve the speed of services or the effectiveness of organisational procedures. RTLS has existed since the 1990s, when it was first described as *'a new technology that leveraged the automatic identification capabilities of radio frequency identification (RFID) tags, and provided the ability to view the location of a tagged object on a computer screen'* (Khudhair et al., 2016).

RTLS has many applications in different industries; examples can be seen in Figure 3.4. The market of RTLS is currently growing at an estimated annual rate of 38%, and its applications continue to increase (Brena et al., 2017).

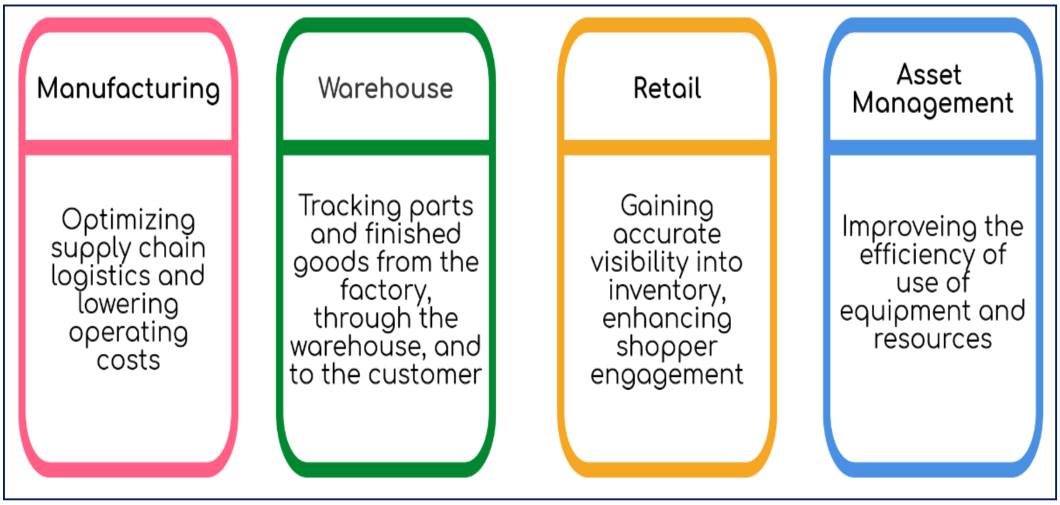


Figure 3.4 Real-time locating systems (RTLS) Applications

3.3 Types of Indoor Locating and Real-Time Tracking Technologies

There are four primary positioning systems: global position systems (GPS), infrared-based systems, ultrasound-based systems, and Radio Frequency-based systems. Of these, radio frequency-based systems, as seen in Figure 3.5, provide the environment for the popularised indoor locating systems. These include Radio Frequency Identification (RFID), Wireless Local Area Network (WLAN/Wi-Fi), Bluetooth, ZigBee, Ultra-Wideband (UWB), FM radio, Near-Field Communication (NFC), and systems that are a hybrid of other positioning technologies. Although, GPS is best for outdoor use, Infrared Radiation (IR) is a common positioning system often used to track devices and links over short distances, between devices such as computers or mobile phones. IR is also used to transmit information from place to place, including: remote controls for television sets and DVD player. IR-based devices are small and lightweight. They can be used for indoor location, but have expensive hardware issues and raise privacy concerns. Ultrasound systems use ultrasound signals, reflected off walls, or other indoor obstructions, for estimating the position of the emitter tag, based on the way bats operate. Ultrasound lacks accuracy and suffers from interfering signal propagation, such as when nearby metals collide with each other (Brena et al., 2017).

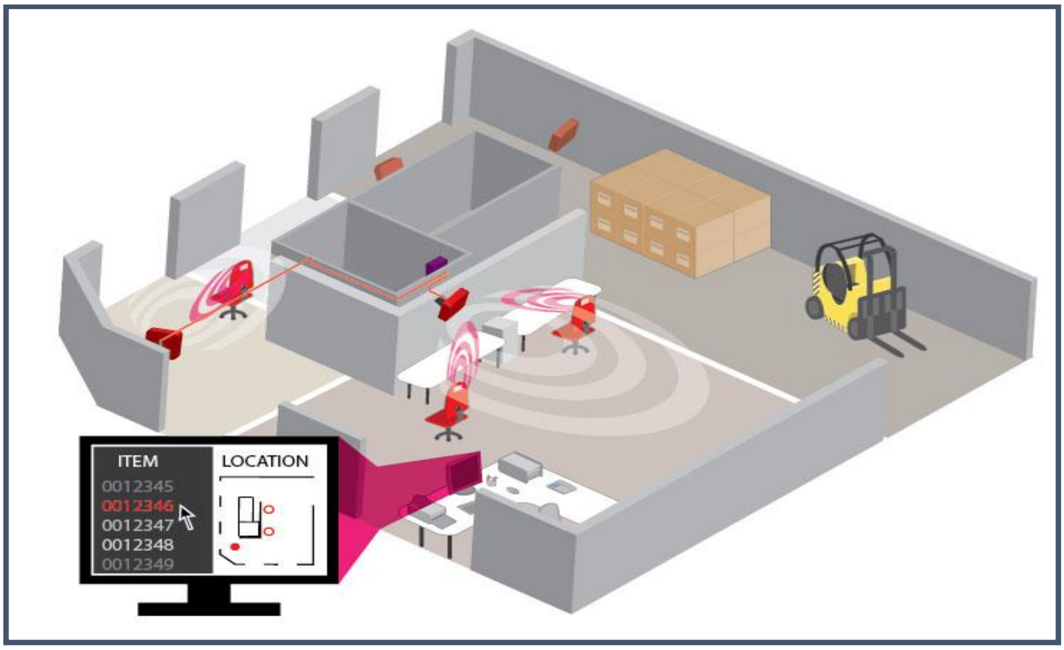


Figure 3.5 Indoor Positioning System (Radio Frequency-based Systems). Source: Haddud et al., 2015

Radio Frequency (RF) technologies, on the other hand, have more uses, since they can penetrate walls and other solid obstacles. RF also has greater coverage with reduced hardware demands. RF technologies are divided into narrow band-based technologies, as previously outlined, and Radio Frequency Identification (RFID) offers the most promising applications to healthcare.

RFID *'enables wireless communication using a non-contact advanced automatic identification technology that uses radio signals that put an RFID tag on people or objects'* for identification, tracking, and management purposes (Farid et al., 2013). The tracking is done by a network of radio-enabled devices within a range of several metres. RFID system components include: tag, antenna, reader and computer as illustrated in Figure 3.6.

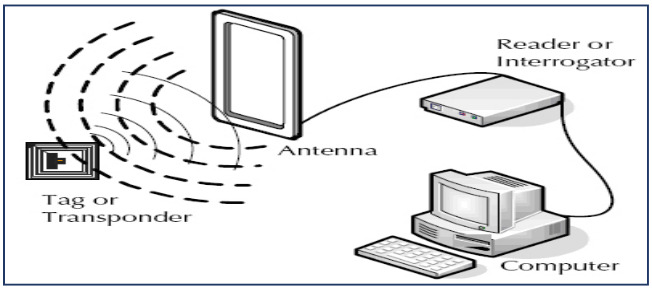


Figure 3.6 Radio Frequency Identification (RFID) System. Source: www.epc-rfid.info (2018)

WLAN positioning systems locate nearly all Wi-Fi compatible devices without requiring a line of sight. This advantage has caused WLAN positioning to become one of the most widely used indoors locating approaches. WLAN, however, requires more costs, due to the built-in network interface cards that measure signals from all access points within the receiving range. This means that the location is found directly from these network interface cards (see Figure 3.7). With the abundance of mobile devices capable of GPS, WLAN has also a scalability advantage. However, the signal strength is sometimes unreliable, and interference with other appliances in its wave frequency is possible (Chowdhury et al., 2016).

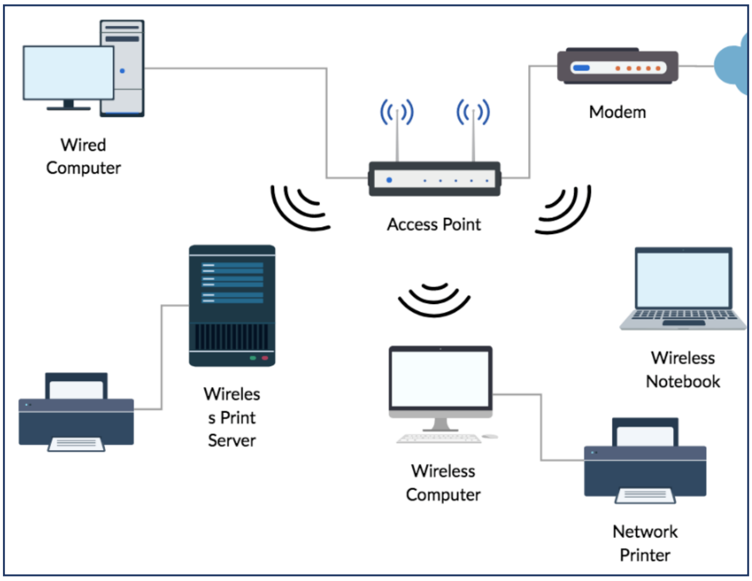


Figure 3.7 WLAN typical network. Source: http://dangtinbdshanoi.com (2018)

Nearly all Wi-Fi-enabled mobile devices are embedded with Bluetooth functionality. **Bluetooth** has the ability to transfer data quickly between devices located in proximity to one another. It requires low cost, is small in size, and has a high level of security. Bluetooth must run the device discovery procedure each time it operates its location finding, which increases latency to between 10 and 30 seconds, results in high power consumption, and can overload the software. Consequently, Bluetooth is not a preferred solution for real-time location services in healthcare operations (Aguirre et al., 2016).

ZigBee is a relatively new wireless technology standard, useful for short and medium range communications. ZigBee Alliance was founded in 2001 for the purpose of researching this new technology for the provision of additional communication standards. It is useful for applications requiring low power consumption and low-rate data communication, and it has a coverage of between 20 and 30 metres (Aguirre et al., 2016). ZigBee runs on a network composed of the Coordinator, the Router, and the End Device. It is currently being applied in industry for control and wireless location, in home networks, such as Smart homes, for building automation, for locating medical equipment, and for many other applications. The greatest shortcoming of ZigBee is unexpected data loss, due to frequency interference and a decrease in stability, derived from the Coordinator carrying too many nodes (Brena et al., 2017).

Ultra-wideband (UWB) uses RF for *'short-range, high-bandwidth communication holding the properties of strong multipath resistance'* (Farid et al., 2013). Its application is preferred over other technologies when high accuracy (within 20 to 30 cm) is required, but UWB hardware is expensive (see Figure 3.8). FM radio also uses RF technology and has held widespread usage for decades, due to its installation in vehicles and households. FM radio splits its band into frequency channels used by stations. These channels vary in range and distance from one another for different regions. (He & Chan, 2016).

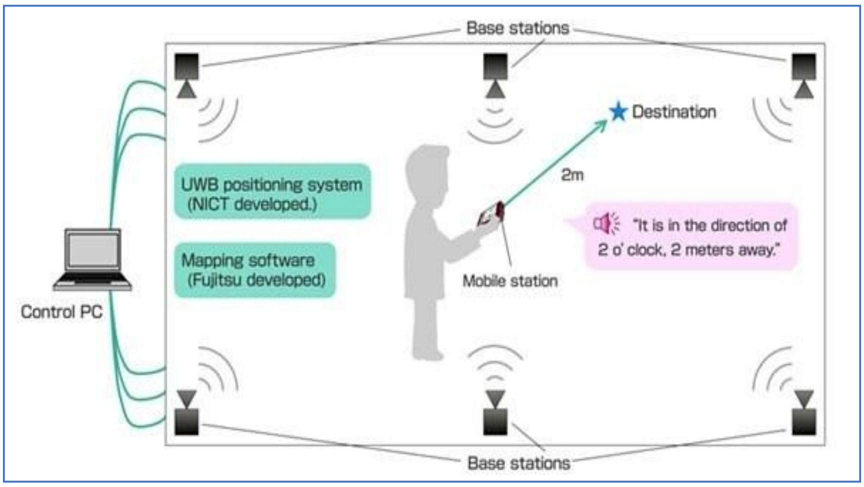


Figure 3.8 An example of indoor navigation using ultra-wideband (UWB). Source: www.engadget.com (2018)

Near-field Communication (NFC) allows for two devices, one of which typically is a mobile device such as a Smartphone, to communicate when within 4 cm of each other. Popular uses are: contactless payment systems, unlocking doors, or checking in to a location (Tom, 2016). More examples of NFC applications can be seen in Figure 3.9.

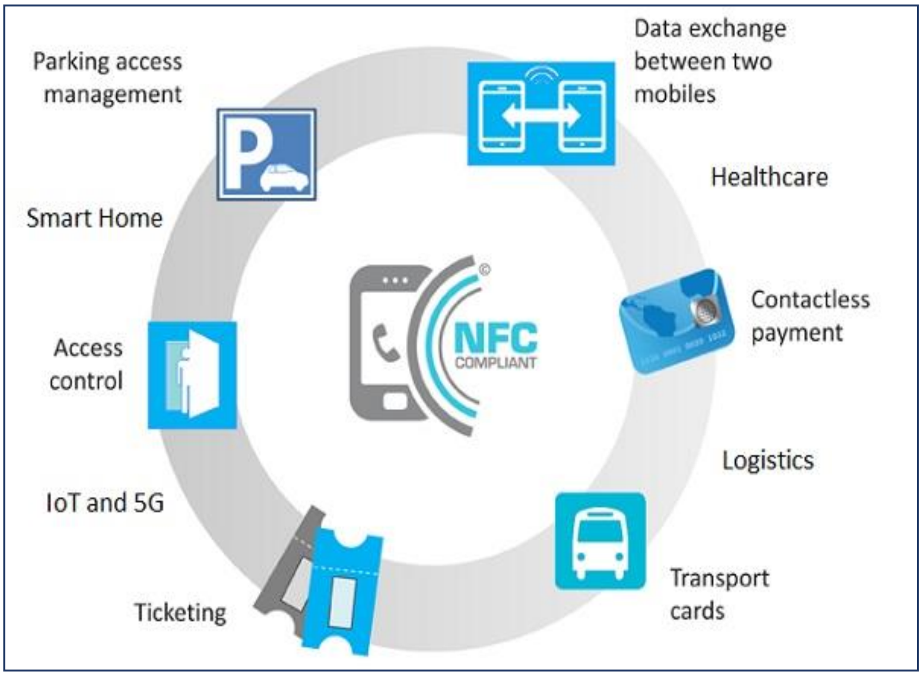


Figure 3.9 Example of Near-field communication (NFC) Applications. Source: https://www.rfpage.com (2018)

Hybrid systems combine two or more different positioning technologies to determine the mobile client's location. These systems often exist because of the need to adapt either indoor or outdoor environments, so that if and when GPS fails, a coexisting system may act as a backup. Applications such as Google Maps rely on GPS, but have begun to map building interiors as well, so the ability to place the mobile client, based on cellular positioning systems, inside the building, allows the user's location to remain uninterrupted (He & Chan, 2016). As it concerns health monitoring, there are five categories of detection methods, which are outlined as follows:

1- **Wearable devices** are embedded with sensors and are wirelessly attached to the data processing and communication devices. These devices are currently capable of monitoring in real time qualities such as vital signs, physical activity, and sleeping patterns. Most wearable devices transfer data via Bluetooth, to be stored in a mobile phone or a computer.
2- **Wireless-based techniques**, are based on the Wireless Body Area Network (WBAN), which is a wireless sensor network. WBAN *'provides the automatic real-time acquisition of vital signs to ensure flexibility and keep up patient mobility'* (Ehrenfeld, 2015). WBAN uses wearable devices along with mobile devices and wireless network devices, to manage patients' health conditions. WBAN typically employs Bluetooth, RFID and ZigBee.
3- **Ambience devices** use multiple sensors in a closed area with a local computer to gather data on the surroundings. Its purpose is usually to detect abnormal events such as vibration from a person falling.
4- **Vision-based methods** use cameras for tracking people. This is a resource-intensive approach that also has shortcomings such as line of sight, as well as invading people's privacy.
5- **Floor sensors** are currently in use for the development of such products as "Smart carpets" which use sensors to detect when people fall.

3.4 Smart Hospitals

Many kinds of devices currently operate within hospitals, in order to improve procedures and patient care. Medical devices allow for hospitals to become fully interconnected, with data being linked seamlessly between devices and systems. According to Mertz (2014), a Smart hospital is a place in which '*existing technologies are designed, set up, and integrated to share data back and forth, and ultimately to provide an enhanced level of clinical information, to* *enable diagnosis, to monitor treatment, and to provide metrics to see how a hospital is performing*.' Although basic information technologies have existed for decades in hospitals, new technologies are constantly being developed that add new layers of information for faster systems and better metrics. When these technologies were originally being developed, interoperability was not a focus, and the devices and systems became convoluted and simply existed together for a while. One solution to the lack of cohesion in systems has been, for places like Fisher-Titus Medical Centre in Ohio, to reduce fragmented information by partnering with an electronic medical record company in 2009. This provided a single system responsible for capturing all patient data, and by 2013 allowing patients to access this information as well through an online portal (Mertz, 2014). These technologies always provide some form of user interface, such as a Smartphone application or computer screen, providing patients remote access to their medical records. This is always a benefit, as long as security is high, since it increases transparency. Further trends in Smart hospital are illustrated in Figure 3.10.

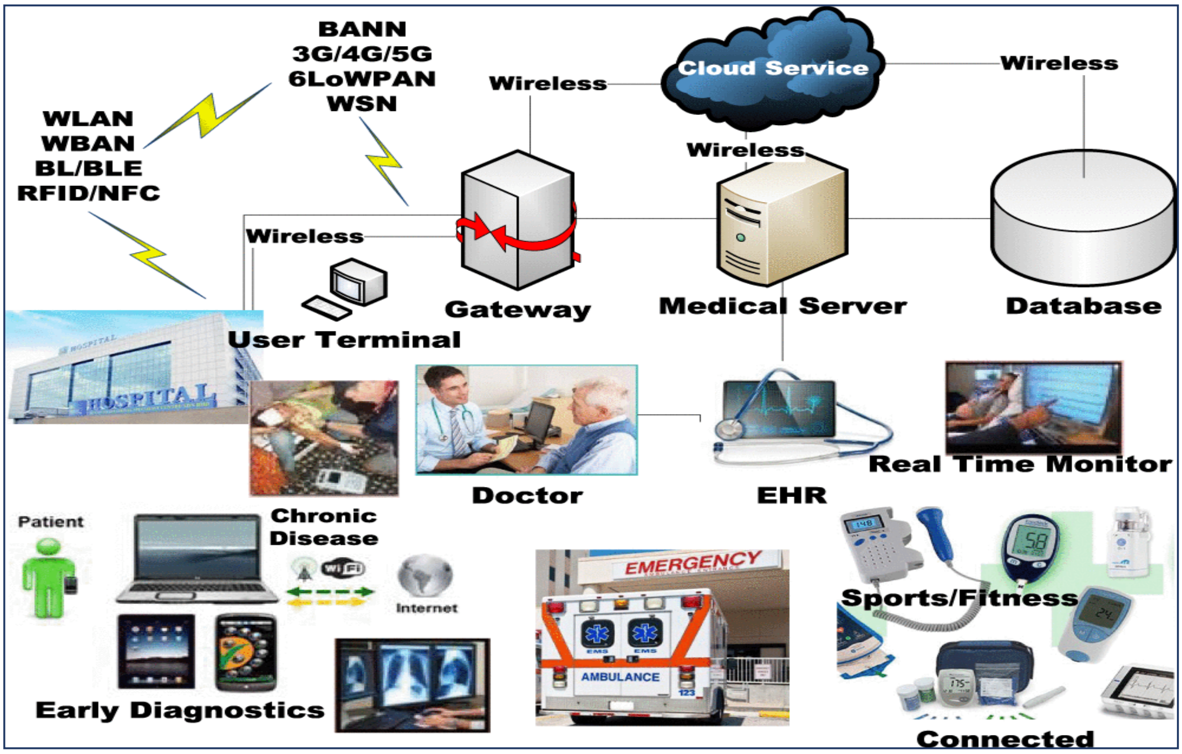


Figure 3.10 Smart Hospital trends. (Riazul Islam et al., 2015)

A Smart hospital standard is not yet in place, but some research aims to remedy this. Alharbe and Atkins (2016) specify that a Smart Hospital System (SHS) '*provides innovative services for the automatic supervision of both patients and personnel within hospitals or nursing institutes through the deployment of an IEEE 802.15.4-based Wireless Sensor Network (WSN)* *able to collect and deliver data to a Central Server*' (Alharbe & Atkins, 2016). Such a system integrates Ultra-High Frequency (UHF), RFID, and WSN technologies. The system is connected by a network of nodes, relayed to the relevant hospital staff, and ideally it is accessible through a mobile application (app) for easy interaction and visualisation. The mobile app provides push notifications, usually activated in emergencies, while storing readily available information on the patient. Organisations such as The European Union Agency for Network and Information Security (ENISA) introduced Smart hospital objectives, as can be seen in Figure 3.11.

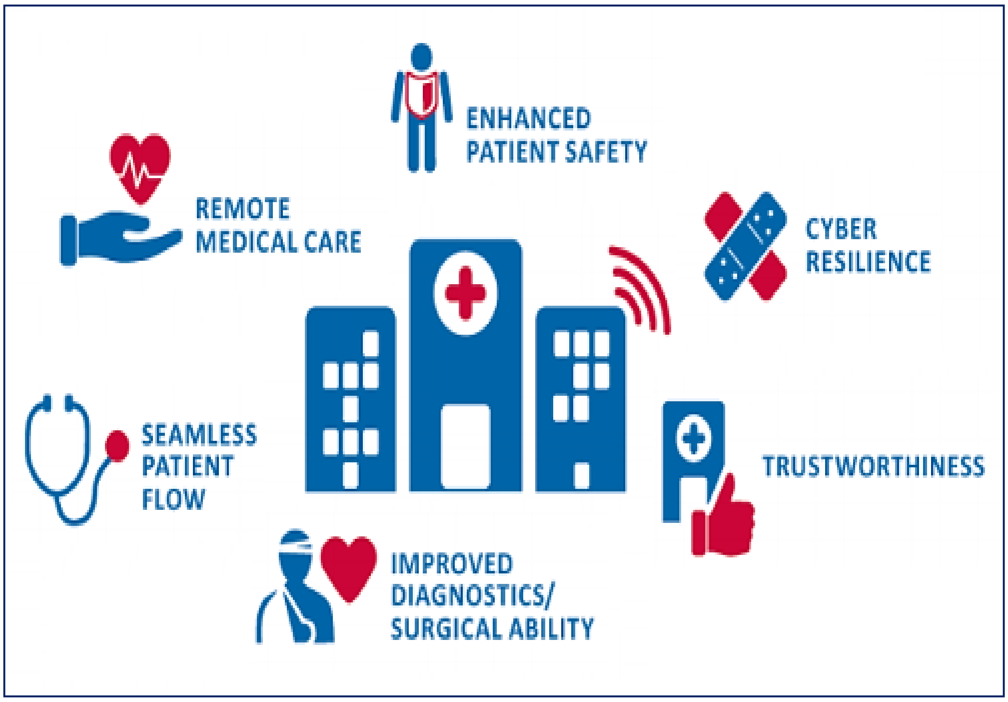


Figure 3.11 Smart hospital objectives. Source: ENISA, 2016

3.5 Using Locating and Real-Time Tracking Technologies to Improve Flow and Optimisation in Hospitals

There are seemingly endless applications in medical facilities where hundreds of people are responsible for the care of other people's lives. At nurse stations, intelligent technology can provide information for medical service status, environmental conditions, equipment management, intelligent displays units, and call functions. The operating theatre requires proper electrical distribution, a surgeons' panel, and environmental control. Besides these, intelligent technology is now needed for data centres, energy departments, general wards, isolation rooms, midwifery units, mental health units, and more. Electricity and energy consumption, lighting, fire protection, and HVAC and temperature control are only some of the aspects relevant to all rooms of a hospital. Well-established intelligent technology infrastructure allows patients to have more choices in their healthcare options and locations, allows practitioners more access and monitoring of their patients, and provides practitioners with better results for patient assessments (Zafari et al., 2017). It is important to understand how patients proceed through the care delivery system (Ogden et al., 2017). The best way to achieve this is through process mapping, as shown in Figure 3.12.

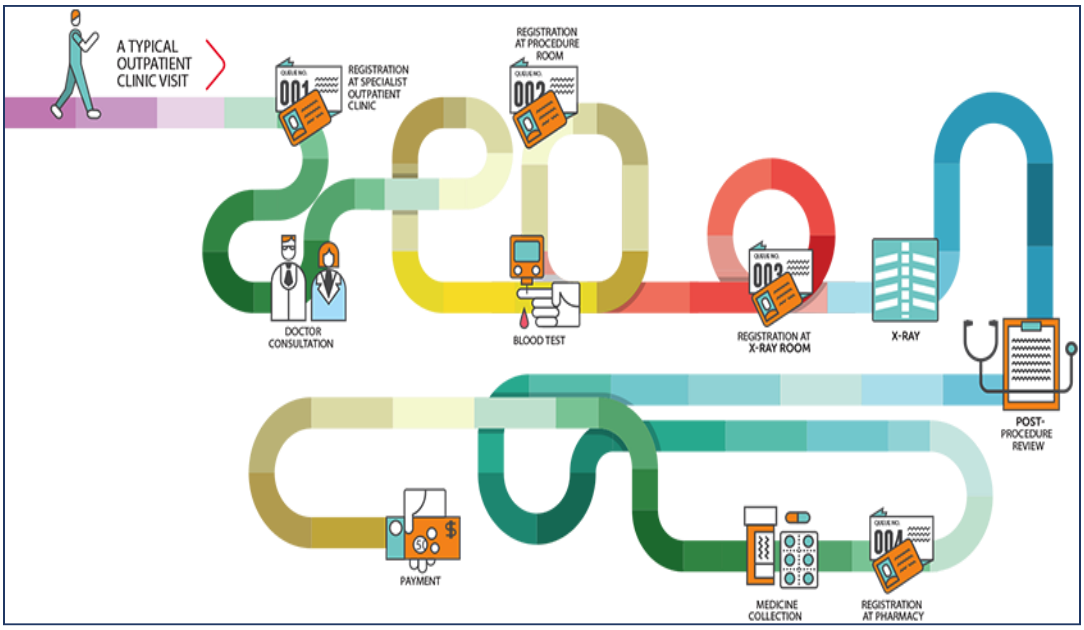


Figure 3.12 Hospital Flow & Patient Journey Process Layouts. Source: www.ntfgh.com.sg (2018)

In addition to this cross-sectional perspective of Smart technology, as it integrates into every aspect of hospitals, this technology is utilised best when it is integrated as a process and is analysed over time. Each patient's individual journey, from admissions to discharge, is a useful source of data that allows new technologies to adapt to diagnosed shortcomings and failures. Increasing efficiency of systems is vital, as healthcare costs are increasing in many countries. The World Health Organization reported in 2010 that $335 billion was wasted in healthcare in the United States alone *'due to the lack of interoperability of information systems'* (Zafari et al., 2017). Some technologies utilise the changes enabled from existing technologies, to dramatically reduce cost. Telehealth, which is *'the use of electronic information and telecommunications technologies to support long-distance clinical health care, patient and professional health-related education, public health and health administration,'* uses integrated Smart technologies to reduce care costs by nearly 50% (Bossen et al., 2015). Emerging technologies will continue to expand the coverage of Telehealth and range of services offered in this manner (Dwiyasa & Lim, 2016). More benefits of introducing Smart hospitals applications can be seen in Figure 3.13 (ENISA, 2016).

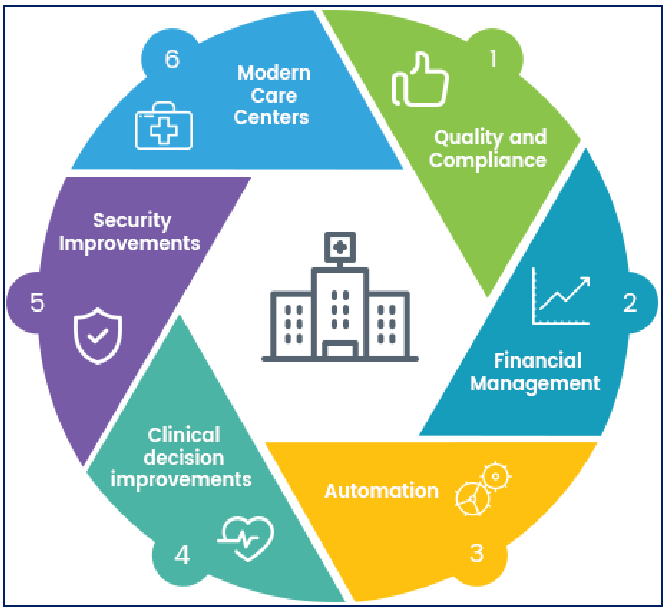


Figure 3.13 Smart Hospital Benefits. Source: ENISA, 2016

Some of the benefits of features used in Smart hospitals include reduced average length of patient stay, increased patient safety and satisfaction, and improved financial performance and management systems. Organisations typically must put forth a significant investment when developing Smart capabilities, which is why the level of intelligent technologies employed in medical facilities varies greatly (Robertson, 2013; Alharbe & S. Atkins, 2014; Drazen & Rhoads, 2012). Since each kind of device has the potential for RTLS integration, a hospital may pick and choose from a list of options based on their specific needs. Drazen and Rhoads (2012) suggest that best practices for using technology in hospitals include:

1- *Viewing patient flow as a system-wide phenomenon requiring system-wide attention.*
2- *Waiting to introduce the new technology until processes have been reviewed and tended to.*
3- *Selecting a new system based on the specific levels of precision needed for the organisation.*

4- *Setting goals and parameters for the tracked processes.*
5- *Using a team with members spanning the organisational structure to identify areas for improvement.*
6- *Remembering that the goal is improved care and not to monitor productivity.*
7- *Analyse the changes in the details of the processes*

It is important to note that these technologies come with trade-offs of costs and benefits, with many factors to be considered. Proper integration, such as expanding services to Telehealth, means that patient care can be improved without significant extra costs being incurred. Although patient flow and tracking are major aspects of improvement, process optimisation is vital for system-wide efficiency and accuracy. Process optimisation is achieved through workflow optimisation, lean management, predictive modelling, and patient flow simulation. Depending on the organisation, patient tracking can be done either by RTLS or through the use of event-driven data. Event-driven data deduces the location of patients through changes in their last-known location or status, often through manual entries or by being imported from hospital information systems. These event-driven systems emphasise visibility of system-wide status regarding patients' location and condition. Drazen and Rhoads (2012) outline the interaction between process and technology in order to determine which system is best for an organisation: *'While process redesign is necessary in order for technology-based solutions to work, technology can also help organizations get the most out of process redesign. Tracking tools can provide deep insight into how processes actually work and where bottlenecks occur. Tracking systems capture valuable timestamps and location data, which can be used in queuing models, forecasting tools, and discrete event simulation.'* These models, tools, and simulations are advanced techniques, but often they are not sufficiently used in order to implement the proper solution, due to the lacking of sufficient awareness by healthcare executives.

It was estimated worldwide that between 1 and 5 percent of medical facilities had adopted patient flow technologies (Sorenson et al., 2013). Patient tracking technologies are not yet being used in the operating room, and this is often the bottleneck. Patient flow initiatives for the operating room implement traditional process improvement strategies like Lean Manufacturing or Six Sigma. Adjusting scheduling, either in the operating room or for staff, is a task with often significant benefits (Drazen & Rhoads, 2012).

3.6 Comparison of Indoor Locating and Real-Time Tracking Technologies in Healthcare and Smart Hospitals

When choosing between the many indoor locating and real-time tracking technologies for use in medical facilities, many factors must be considered. These include the accuracy, coverage, frequency, applications, advantages and disadvantages, etc. (Brena et al., 2017). The acceptable accuracy levels in RTLS technologies can be described as follow: -infrared are reliable up to 1 m, -WLAN/Wi-Fi and Bluetooth typically are reliable up to 2 to 3 metres, and -ZigBee and RFID are reliable up to 10 to 20 metres. This may be a significant factor in an organisation's decision. However, these ranges do vary. Cheap or older cameras may only be accurate to the centimetre or metre when locating an object far away. For coverage purposes, Wi-Fi, RFID, UWB, and ZigBee provide the best solutions. Wi-Fi systems sometimes have a range of 20 m, but inexpensive add-ons can scale up this range considerably, often to 50 m. Both RFID and UWB range up to 50 m as well, and ZigBee extends to 20 m (Schmidt & Hildebrandt, 2017), but this requires unobstructed line of sight. Bluetooth can reach 15 m, which can occasionally be limiting on a floor-wide basis for a hospital. Cameras are dependent on their line of sight, usually no more than 10 m. Infrared is limited to 5 m and is also limited to tracking one device at a time. NFC is also line of sight dependent, and although there exist security and privacy concerns, its design is based on a range of no more than 10 cm, to ensure that data is transferred only when desired.

A list of the technologies is ordered from lowest frequency to highest frequency as follow:

- RFID (ranging from low frequencies of 30-500 kHz, to high frequencies of 3-30 MHz, and ultra-high frequencies of 860-960 MHz),
- NFC (13.56 MHz), Wi-Fi (902-928 MHz),
- Bluetooth and ZigBee (2.4 GHz),
- UWB (6-8 GHz),
- Infrared (3-30 THz), and
- Cameras (300 THz).

Frequency interference is always an issue when these ranges are wide, or when there are multiple systems in proximity, but the most prevalent issue stems from Bluetooth encountering data loss from frequency interference. Applications often overlap between these technologies;

it is this occurrence that requires a decision to be made as which is the better of the two or more that qualify. Most useful for tracking are ZigBee, RFID and NFC, whether it is for products or people. Both cameras and UWB are being applied in robotics and in automation, such as for assisted driving or parking. Although applied to personal healthcare, Bluetooth is also useful for building automation and industrial control, such as for implementations in Smart home, where a smaller range than for a hospital is preferred. As mentioned before, NFC applications require close-range receivers, so door access or contactless payment or identity confirmation are common applications. Wi-Fi is not typically used for tracking products, but it can assist with pedestrian navigation and location-based services. Cost is inevitably a large factor when a hospital considers a system-wide change in technology. Among these technologies; RFID, ZigBee and Bluetooth are the lowest in cost. However, cameras, infrared, UWB and NFC typically require heavy infrastructure investments, possibly because these technologies tend to have a lower range. Technologies known for their lower degree of power consumption are RFID, UWB, and ZigBee. Bluetooth and Wi-Fi demand large amounts of power, sometimes requiring devices to be recharged after 12 hours, as opposed to months of use between charges for ZigBee devices (Dwiyasa & Lim, 2016). For the purpose of this research and, in order to develop an RTLS system, eight technologies were compared in terms of accuracy, coverage, frequency, typical application, advantages and disadvantages, as shown in Table 3.1.

Table 3.1 RTLS Technologies Comparison

Technology	Typical Accuracy	Typical coverage (m)	Frequency	Typical application	Advantage	disadvantage	References
Cameras	mm – cm	1 – 10	300 THz	Metrology, navigation, automation	Covers a wide field.	High cost, low accuracy levels, unable to track multiple objects individually, light reflections.	(Xiao et al., 2016; Chen et al., 2014; Samu, 2017; Chowdhury et al., 2016; Yassin et al., 2017; He & Chan, 2016; Farid et al., 2013)
Infrared	cm – m	1 – 5	3-30 THz	People detection, tracking	Reliable, accurate	High cost, easily interfere with other systems, unable to track multiple objects, does not penetrate walls	
Bluetooth (IEEE 802.15)	m	10 – 15	2.4 GHz	Mobiles, communication, tracking	Small Device, easy to integrate with the PDAs, low cost, no line of sight required	High power consumption, requires regular maintenance, easily interfere with other systems	
WLAN/ Wi-Fi	m	20 – 50	902-928 MHz	Navigation, LBS	Using existing Wi-Fi infrastructure, speed, no line of sight required	Low accuracy, very high-power consumption, privacy concerns, signal strength	
RFID	cm – m	1 – 50	LF 30- 500 kHz HF 3 – 30 MHz UHF 433, 860-960 MHz	Logistics, people & product tracking, access control. inventory management	Covers a wide field, penetrate solid, high accuracy, low cost, no line of sight required	User resistance which can be overcome by staff induction and proper training	
Ultra-Wideband	cm – m	1 – 50	6-8 GHz	robotics, automation	low power consumption	High cost of UWB equipment, subject to interference caused by metallic materials	
ZigBee		10-300	5725-5850 MHz 2.4 GHz	Personal healthcare, building automation, industrial control	low power consumption, battery life, high reliability, scalability, highly secure	Cost	
Near field communication (NFC)	cm-m	1.4 -23	13.56 MHz	Door access, payment, identity, goods tracking	synchronization not required, low power consumption	line of sight required, cost, security concerns, privacy concerns,	

3.7 Radio Frequency Identification (RFID)

Since one of the major goals of the healthcare industry for the 21st century is to successfully adopt and implement information technologies, it is critical to understand the most commonly used and fastest growing technology, which is that of radio frequency identification (RFID). For years, RFID has been referenced as *'the next wave of IT innovation that will widen the healthcare transformation'* (Dwiyasa & Lim, 2016). This section explores the literature on RFID, followed by a description of the RFID system components, and then analyses its use in the healthcare industry.

3.7.1 RFID Overview

RFID encompasses technologies that use radio waves and can identify thousands of tags on items per second, all performed wirelessly. This means that multiple tags are read simultaneously, as opposed to traditional barcode systems. Human error is also eliminated through RFID, since these tags can be tracked automatically. RFID is categorised as a *'wireless auto-identification and data capture (AIDC) technology'* (Yazici, 2014). Information is then stored on computers and requires no manual data entry. RFID tags are classified as either "active" or "passive", with active tags being both higher in cost (from $15 to $100 for active versus $0.15 to $5 for passive) and range (100 metres versus 3 metres). Active tags are best suited for tracking purposes, whereas passive tags are used for identification (Cheng & Kuo, 2016).

Applications of RFID are classified into groups of asset control and management, monitoring of human activity, and integration of people and assets (Winston, 2016; Hong & Sung, 2015). Products can be better controlled with the application of RFID, since their locations and status are always known or the information is easily accessible. This ensures products are used before expiration and that inventory levels are kept at reasonable amount. Studies have shown that RFID technology reliably checks, tracks, and traces products, and facilitates inventory management. Workflow has improved for the betterment of patient management, as demonstrated at the Seoul National University Bundang Hospital (Khudhair et al., 2016), and time is saved by staff, due to a decrease in search time for products, as at the Texas Health Presbyterian Hospital in Dallas (Kim et al., 2010; Fosso Wamba et al., 2013b). Yazici (2014) argues that RFID provides benefits, including (but not limited to): increased productivity, increased efficiency, cost savings, reduced theft loss, reduced waste, improved patient care quality and safety, better regulatory compliance, improvement of work environment and conditions, and the improved synchronisation of product flow and information flow. The combination of these benefits is a major reason why most hospitals have adopted RFID into common usage. Roper et al. (2015) found that RFID is superior to barcode technology in almost every aspect, including data recording and capacity, tag technology, durability, tracking, and inventory management. It is equal in accuracy; and is only inferior in terms of its electromagnetic interference qualities and in its cost (Roper et al., 2015a). RFID system components include: tags, antenna, reader and host system/computer as illustrated in Figure 3.14.

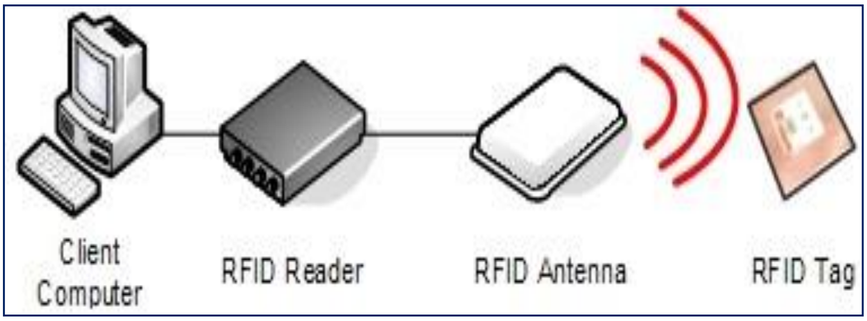


Figure 3.14 Typical components of RFID System. Source: www.supinfo.com (2016)

The initial investment for the set-up of an RFID system typically is expensive, so the support of the facility's finance committee is critical (Cao et al., 2014a). Therefore, effective cost control is important for a facility to be suited to adopt RFID technology into its infrastructure. Additionally, since RFID can withstand temperatures between -40 and 200°C it has proven vital at facilities such as Pierrel-Ospedali, an Italian pharmaceutical company that used RFID tags for products requiring prolonged sterilisation at over 120°C (Roper et al., 2015b). Cheng and Kuo (2016) cite enhanced patient safety as the main advantage of RFID implementation, through avoidance of medical errors, and patient tracking (especially important for suicidal patients, for instance), and notification of patient conditions breaching specified levels, or of patients experiencing a fall (Cheng & Kuo, 2016).

Another instance of RFID demonstrating its significance lies in its ability to identify defective medical devices. With advanced tracking now in place, organisations can track production date and time, batch number, and production conditions, to ensure every device meets standards. The UC San Diego Health System was required by the Food and Drug Administration (FDA) to immediately apply automatic warning labels (RFID) on hundreds of infusion pumps. This resulted in reduction of 50% of the staff, as the time for checks was reduced from weeks to 48 hours (Roper et al., 2015b)

The most noteworthy downsides of RFID include its misperception regarding funding needs and returns on investment, together with the complicated integration with other systems, the lack of relevant standards, and increased maintenance cost. There are also privacy concerns, due to the tracking of hospital staff, security and privacy concerns for patient information, difficulties in closing the regulatory compliance gap, and concerns that its underutilisation can negatively impact on the financial returns related to RFID (Yazici, 2014). Many of these concerns can be resolved before implementation, by means of careful and thorough analysis of the hospital's needs, constraints, and abilities. One technologically innovative and not-for-profit hospital in the U.S. was analysed in a case study by Cao et al. (2014). They undertook a "pilot project" for two weeks, in which 128 tags were installed and roughly 50 RFID tags were used. Many of the remarks from the researchers' interviews were positive, supporting the advantages, but they actively sought out constructive criticism. One member of staff reported that the subjects often experienced "jittering", when a person's mobile tag would report to the wrong tags due to a proximity issue, and could sometimes "bounce back and forth" between two tags repeatedly. Cao et al. (2014) noted that the current accuracy rate for RFID detection is around 85%, which is below hospital standards (Cao et al., 2014b).

Concerns have been raised over the batteries, since some have a limited life (2 months), and multiple failures in a short time span is not acceptable in a hospital setting. The solution offered is for more expensive units with longer battery life. Further expense also allows the users to obtain smaller devices. The cost, for this organisation (Cao et al. (2014)), was the reason for the limited pilot, with their best options given at $60 per tag and $2.70 per square foot of wireless infrastructure for the tags to cover. Responses from IT managers at the end of the trial period were mostly favourable, with citations of the potential of RFID and its identification as a possible communications solution. Patient feedback was neutral, but there were no instances of resistance to wearing a tag. The physician interviewed did not see immediate benefits from RFID but did not believe that work processes were affected (Cao et al., 2014). One department at the Complejo Hospitalario Universitario A Coruña (CHUAC) had its adoption of RFID analysed by Peréz et al. (2016), and benefits were seen with more time to adjust to the learning curve. For instance, most incidents detected related to issues in reading passive tags, and to errors in adhesive placement for tags on intravenous mixtures, but these occurrences lessened as personnel gained experience (Pérez et al., 2016).

Wang et al., (2010) and Lai et al., (2014) survey of 133 Taiwanese manufacturers revealed that complexity, compatibility, firm size, competitive pressure, trading partner pressure, and information intensity are most likely to affect their adoption of RFID. The case study performed by Lai et al. (2014) allowed for longer-term exposure (February to November 2011) and surveyed Directors of the information systems of the three hospitals examined. The results showed that some of the issues of hospital personnel in Taiwan were unsubstantiated. Although the cost was deemed “extremely high”, there was no evidence of complexity being an issue, and the hospital staff were supported well enough, so that there were no technical difficulties. The longer-term exposure also allowed for hospital staff to change their attitudes toward the benefits of RFID, as they witnessed optimised processes and shortened patient escort time. One of the Directors, interviewed after the conclusion of the observational study, reported that the decisions of competitors to adopt RFID ‘*did not affect [their] decision-making at all*’ (Lai et al., 2014).

The literature studies by Yao, Chu, and Li (2011) and Coustasse, Tomblin, and Slack (2013) concur that RFID is an innovation with radical changes; Unnithan (2014) cites the global recession as an underlying factor leading organisations to search for cost-effective solutions in resource-constrained facilities. One hospital in Australia (Unnithan, 2014) experienced ‘*silent boycotting of the technology for years*’ due to one set of staff, such as orderlies, telling the nursing staff about how RFID might disrupt their processes. According to the Director of Life Sciences and Healthcare Industry, which is a large consulting practice in Australia, new technology ‘*must be led by a clinician. It cannot be led by an IT person, no matter how brilliant they are or how much they know how to talk the language.*’ Another member of staff interviewed in Australia relayed the importance of including at least one nurse on every team that goes through RFID adoption, to provide reasons of familiarity and trust in the new system (Unnithan, 2014). If a few members of staff feel comfortable with the new technology, then the teams they lead will follow and accept the technology with much higher probability. This is true for any technology system including ZigBee, but especially true for these technologies since they are not in common use within the home (Unnithan, 2014).

3.7.2 RFID System Components

RFID has some similarities with barcodes, such as their ability to fetch information on demand and to facilitate the management of products. However, RFID does not require line of sight. Automated system with no human inference, can transmit data by radio frequency, and can alter the data stored within the RFID tag chip. RFID can read many tags at the same time (Wu et al., 2009). Wu et al. (2011) describes the typical RFID system as one with *'an integrated collection of components including a tag, antenna, reader, and software (or middleware). The tag can transmit information concerning the object to the RFID reader via an antenna'* (Chen et al., 2014b).

RFID can be integrated with a wireless communications mechanism or with a physiological sensing device. The design components for data extraction include several components/layers, including an A/D convertor, a signal receiver, and a sensor device, as illustrated in Figure 3.15. In combination, they receive and convert a signal from the sensor, with the communication interface transferring the information to the RFID reader (Chen et al., 2014b). Development of RFID tags has focused on increasing integration density in chips; these tags are produced by companies like Fujitsu with 64 Kb of memory, which is a large amount of storage space, considering its needs (Palipana et al., 2017).

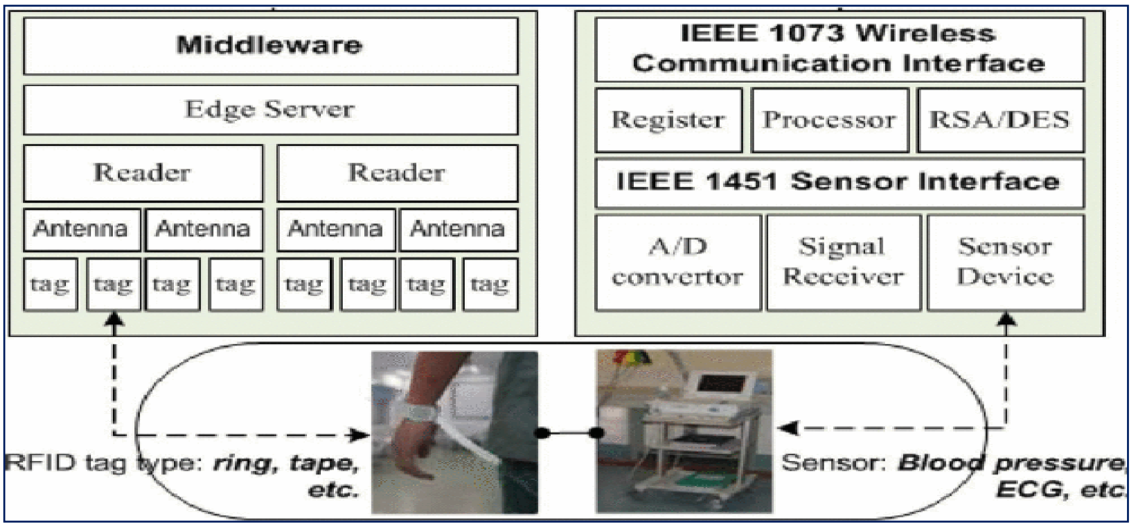


Figure 3.15 Architecture of the Data Extraction Layer. Source: (Chen et al., 2014b)

3.7.3 RFID in Healthcare

High demand for accuracy means that applications of RFID in the healthcare industry are numerous. Common practices currently in place with the assistance of RFID include automated admissions, screening and treating processes, and the enhancement of communications between caregivers and support teams, via the strategic placement of RFID readers within the hospital (i.e., at entrances and exits, operating rooms, offices, etc.) (Manzoor, 2016a; Wu et al., 2009). RFID has also allowed greater access control for both staff and patients, such as for permissions, and can be applied to restricting certain medical equipment to specified locations. Attaching RFID tags to equipment and products helps with inventory management, since the product's quantities are easily known, and fake drugs are identified (Palipana et al., 2017). Using RFID for Smart hospitals requires many assets and people to be tagged, and these tags can come in the form of wristbands for patients, Smart badges for staff, and self-adhesive labels for physical documents (Manzoor, 2016b). Most hospitals already use RFID tags to track and trace patients and staff, and more than half of the applications of RFID go toward tracking people or medical equipment (Wu et al., 2011). In general, the most common types of RFID applications in healthcare are tracking people, identifying patients, tracking equipment or products, tracking and matching blood samples, logging in an electronic medical record, tracking items through the supply chain, tracking pharmaceuticals, and product authentication – see Figure 3.16.

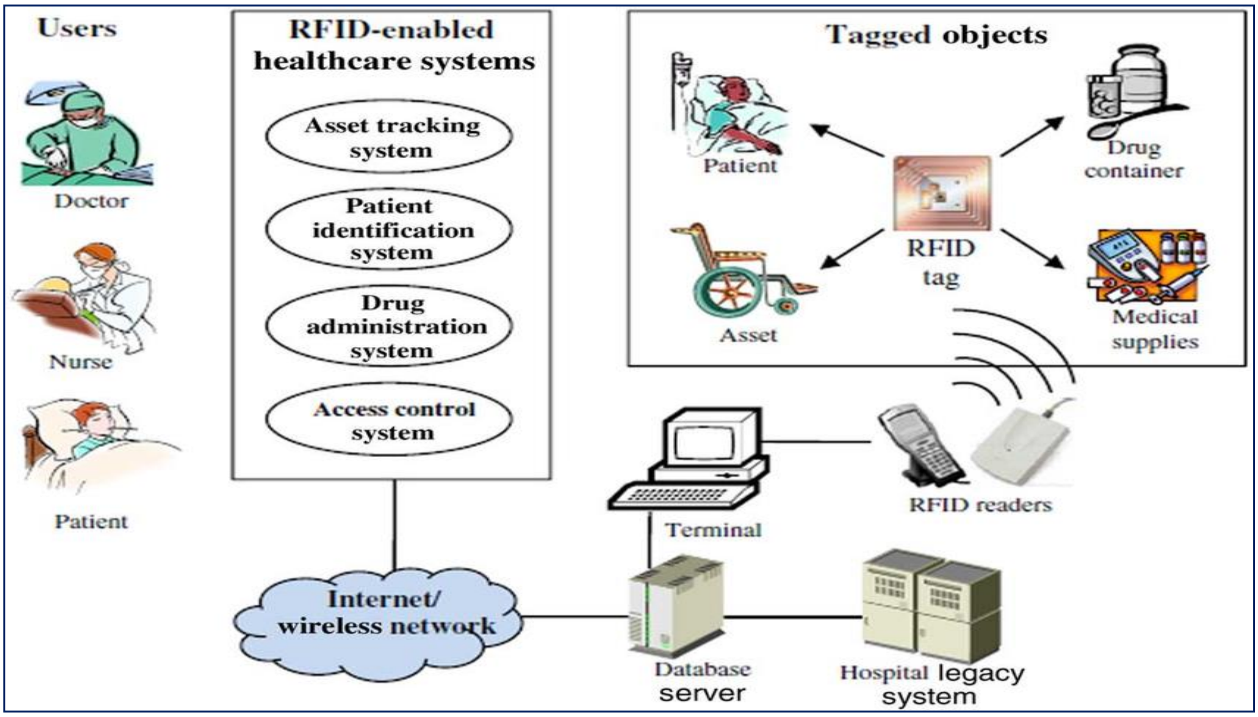


Figure 3.16 Typical RFID-based healthcare system. Source: (He & Zeadally, 2015)

The use of RFID is growing globally at an estimated annual rate of 13.9%, though this rate is even higher, at 30%, in the Asia Pacific region (Manzoor, 2016b). In Taiwan, RFID is in use in retail, logistics, and transportation companies, and demand is growing quickly for RFID in healthcare. Only a few hospitals in Taiwan have adopted its use, with others citing its *'high initial investment and the difficulty to envision the benefits'* (Lai et al., 2014). The expanding market share of RFID has been attributed to more sophisticated healthcare infrastructure, such as the widespread adoption of Wi-Fi across hospitals; and a more collaborative environment between the medical device industry, regulatory bodies, and research organisations. Rising concern for patient safety and for the tracking of expensive medical devices are two more key factors in the proliferation of RFID (Manzoor, 2016b).

3.8 ZigBee

ZigBee is a technology previously chosen for home automation and slow rate data communication – see Figure 3.17 - (Xia et al., 2016). It shares a similar range and frequency with Bluetooth, but has several advantages over this, as well as over the other technologies discussed. This section will provide an overview of ZigBee, describing its system components, and will discuss its promising usage in healthcare system.

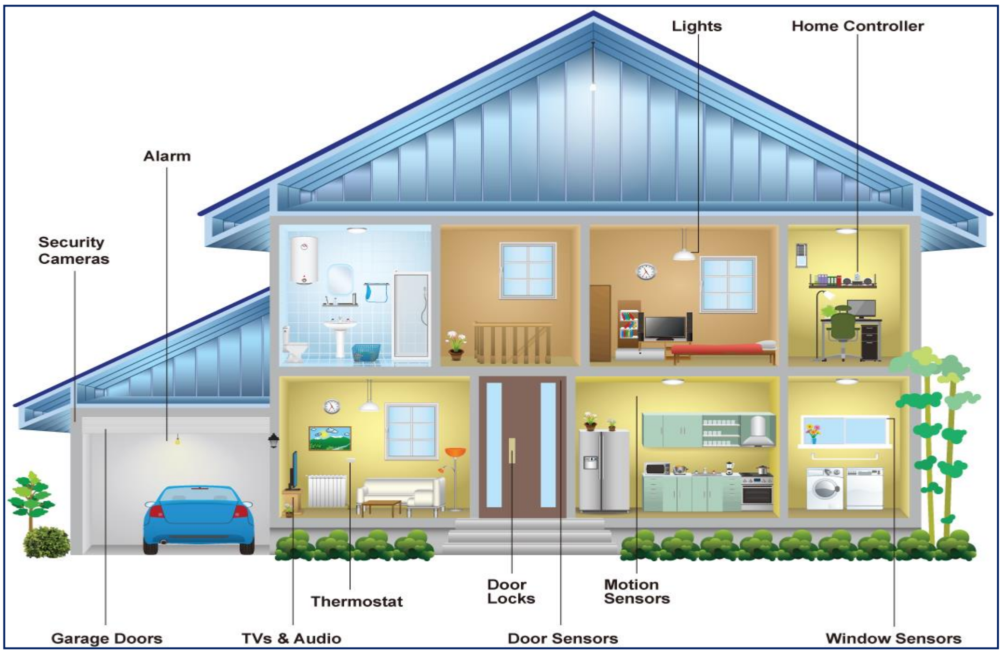


Figure 3.17 ZigBee Home Applications. Source: www.enerwaveautomation.com (2018)

3.8.1 ZigBee Overview

A typical ZigBee network includes: tag, reader, coordinator and personal digital assistant PDA or handheld PC. The collected information will be stored at the system database – see Figure 3.18. ZigBee network sensors use low power consumption and can therefore be operational for years when powered by batteries (Jiang et al., 2017), and ultimately they improve the comfort level of the patients for whom this technology is applied. One of its few shortcomings is that ZigBee has occasional transmission delays and data loss, whenever there is frequency contention.

Unlike RFID, ZigBee operates in only two frequency bands (either 2.4 GHz or 868/915 MHz), supporting 16 channels (Liu & Sahandi, 2009a). Also in contrast to RFID, ZigBee allows for easy installation and low comparative cost for the Coordinator (Jihong, 2011a; Jiang et al., 2017). A single ZigBee network can support and service more than 65,000 nodes, unlike most location systems in which maximum connections rarely exceeds 1,000 (Jiang et al., 2017).

Figure 3.18 ZigBee Network Components. Source: (Alyami et al., 2016)

Since its typical range is roughly 10 metres, ZigBee can only be applied to small size wards, unless multiple networks are installed. In a ward of average size many sensors must communicate with one another, using a single channel, and this is responsible for transmission delays. Additionally, master nodes often overlap their frequencies with those of Wi-Fi, which can result in data loss. Liu and Sahandi (2009) looked at the usage of a single ZigBee network for four patients, and the result was a data loss rate of 26.2%. When they applied multiple ZigBee networks, there was no data loss. This shows that the application of one master node per patient greatly improves the reliability of ZigBee, solving its primary deficiency. The remaining problem is that the overlapping channel frequencies in the multiple ZigBee networks can potentially result in signal interference, though this was not evident from their study. Even in multiple networks, however, ZigBee benefits from its small sensor sizes for easy use in various settings, such as in fitness monitoring, when individuals attach the sensors to their bodies (Alliance, 2009a; Shin, 2008). The low power consumption of ZigBee is of particular value, especially in the light of the concerns expressed over RFID experiencing multiple power failures at unknown times. The ZigBee network uses a patient's (mobile) node and a positioning node The patient's node is embedded in an armband, without the need for any additional equipment (Jihong, 2011b). ZigBee nodes are also classified as Full Function Devices (FFD) and Reduced Function Devices (RFD). FFD are always on and provide network infrastructure, while RFD go through extended sleep cycles and establish one link to an FFD at a time, one FFD of which is the Coordinator.

In the case of Coordinator failure, no other coordinators can join the network, so Scazzoli et al. (2017) suggest guiding the network nodes to switch personal area network identifiers (PAN ID). The observed downtime using this method in a simulation outperformed former methods (resetting the node being the former solution) by an average of 15 seconds, with the downtime results ranging from 7 to 14 seconds (Scazzoli et al., 2017).

Reliable routing of ZigBee networks has been, recently, a primary point of investigation in the literature Multiple traffic patterns exist, such as: - point-to-point (P2P), e.g. a remote control connected to a device; - point-to-multipoint (P2MP), e/g. a controller to all security sensors; and - multipoint-to-point (MP2P), e.g. having scattered temperature sensors around the hospital connected to the controller. Kim et al. (2017) looked at ZigBee under each one of these patterns, using traffic flows of 40-byte payloads sent every 2 or 5 seconds for communication between nodes (Kim et al., 2017). With this slow rate in mind, it is noteworthy to compare this with Singh and Kapoor's (2017) calculation of the maximum throughput of a single hop transmission, which was approximately 115.5kbps, while Aguirre et al. (2016) state that ZigBee communications have a general data rate of 250kbps (Singh & Kapoor, 2017) (Aguirre et al., 2016). Kim et al. (2017) also examined ZigBee under each of its four routing protocols, and found that each protocol must be considered in relation to the needs of the facility. These protocols are: - hierarchical tree routing (HTR), - on-demand routing with possible HTR combination, - many-to-one routing (M2OR), and - multicast routing. Many-to-one routing (M2OR), for example, has a higher packet delivery ratio, better hop count (hops between nodes), and less end-to-end delay than with hierarchical tree routing (HTR) when using 2-second intervals between data transfers. The opposite may be true when using 5-second intervals. In their study across all traffic patterns, packet delivery ratio dropped as node density increased; this decline was more significant than for increasing network size. All four protocols were relatively inelastic in performance as the number of communication pairs increased, though M2OR experienced frequent failure closer to the ZigBee Coordinator. These protocols also must consider memory resources, control overhead, and packet queues (Kim et al., 2017). Possibly one of the most interesting results from Kim et al. (2017) is that *'most of the protocols tend to be insensitive to the growing number of failed nodes, because they quickly found alternative routes.'* This is important for healthcare, where reliability and robustness are critical: hospitals must not lose their operating abilities because of technical problems, and ZigBee shows its ability to notify of failures without abandoning functionality. Two operational nodes beyond their direct range of communication may utilise data forwarding through the best available route within the network. Similarly, nodes can reroute around areas of bad service to overcome coverage deficiencies. ZigBee nodes visually display their working state. Ideally a node would be replaced in case of failure, or else there would be a short downtime if the facility were to react to the warning and respond quickly to the failure (Ding & Song, 2016). ZigBee can also be improved through the coexistence of multiple protocols in a single network, so that nodes can select protocols as they see fit, based on network conditions or traffic patterns. As ZigBee implementation becomes more widespread, due to its reduced cost and better understanding. Their adoption will require to evaluate the organisation's needs and capabilities, so that the developer can optimise the network size, density, and connections in mind (Kim et al., 2017; Aguirre et al., 2016)

Although transmission delays have been acknowledged in ZigBee investigations, actual average transfer time is low, and it takes approximately 30ms (0.03 seconds) to link with a node, thus qualifying it for real-time functions (Jiang et al., 2017). In a simulation by Jiang et al. (2017), 500 nodes were used (with a single Coordinator) over a space of roughly 500 metres by 500 metres, and the test revealed that the server functioned well as long as there were fewer than 1,300 request connections.

3.8.2 ZigBee System Component

ZigBee technology is composed of stack architecture. It is comprised of: - a physical (PHY) layer, with two separate frequency ranges, that directly controls and communicates with the radio transceiver, and selects the channel frequency; - a medium access control (MAC) sub-layer, which controls access to the radio channel, guarantees time slots, and handles node associations; - a network (NWK) layer, which is responsible for discovering one-hop neighbours and storing neighbour information; - and an application layer, which maintains tables for binding and forwarding messages between devices – see Figure 3.19. The application layer includes an application support sub-layer (APS), ZigBee device objects (ZDO), and manufacturer-defined application objects (Phyo et al., 2015; Wang & He, 2011).

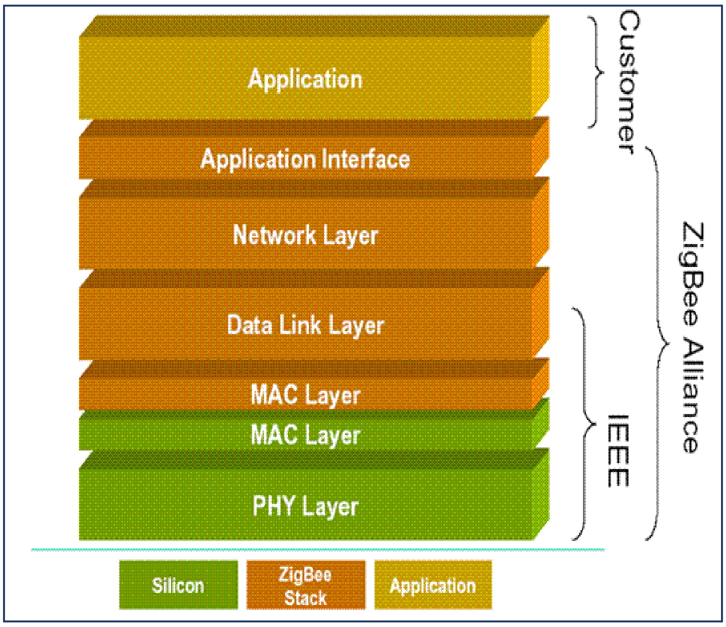


Figure 3.19 Structure of ZigBee and IEEE 802.15.4 architecture. Source: (Wang et al., 2014)

As this is stack architecture, each layer's set of services is performed from the layer above, with a data entity transmitting the data and a management entity providing all other services. A system of ZigBee technology uses a network of devices, consisting of the Coordinator, router and end device, with nodes storing information for access by the Coordinator – see Figure 3.20 (Wang & He, 2011). ZigBee uses a positioning algorithm based on the received signal strength indication (RSSI) value, which decreases with increasing distance (Jiang et al., 2014). According to Liu and Sahandi (2009), *'a single ZigBee network can support only a small number of patients due to its limitations,'* so they propose the solution of applying a ZigBee-based network for each patient.

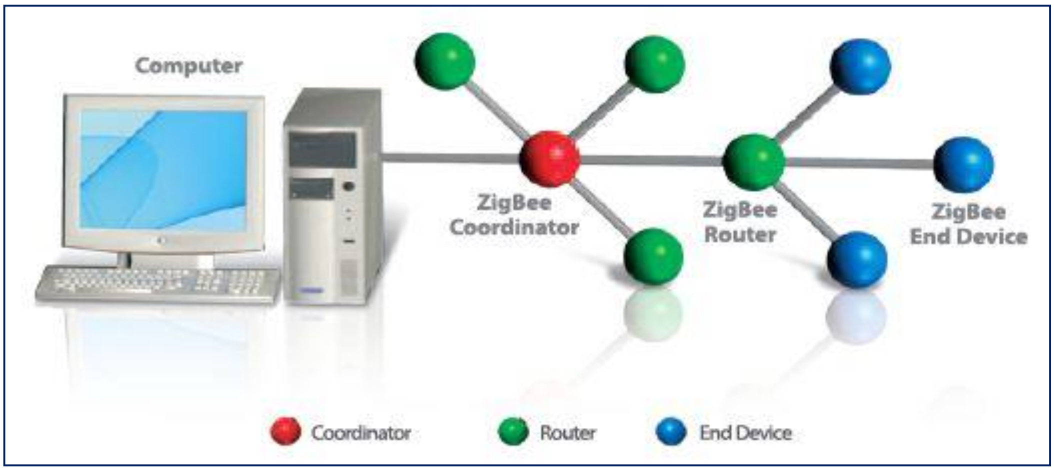


Figure 3.20 Typical ZigBee Network. Source: www.moxastore.com (2018)

3.8.3 ZigBee in Healthcare

As ZigBee has been in use for years for home automation, it is logical that it has become used more frequently in the healthcare industry for building automation, medical equipment control, and providing better safety systems. In a Smart home, ZigBee monitors and controls many aspects of the home, such as temperature, lighting, and movement of objects like curtains (Wang & He, 2011). Applied to healthcare, ZigBee is best suited to monitoring patients in varying capacities. Chronic disease monitoring is possible by tracking specific indicators for episodic patients and identifying the progression of, or recovery from, the illness. This us achieved by continuously monitoring patients with acute conditions, and by monitoring patient's conditions for pre-set scenarios that triggers an alarm upon the breach of the condition – see Figure 3.21. Additionally, ZigBee can monitor people's personal wellness, with the focus being on individuals age 65 and older (Alliance, 2009b). In 2017, Zhongshan Houyuan Electronics Technology in China developed a device designed for the elderly, using a ZigBee network It incorporates a backrest, seat, massage head, signal transmitters and receivers, pressure sensor, frequency sensor, and computer. This device is high in reliability and comprehensive in function, which means that ZigBee technology is being used among the transmitters for the ultimate user benefit (Patent, 2017). For younger people, personal fitness is another application, for monitoring activity, body temperature, and blood oxygen level. Products marketed by ZigBee producers include glucose meters, pulse oximeters, electrocardiographs (ECG), and social alarm devices (for detecting falls, alerting for situations needing emergency care) (Alliance, 2009b).

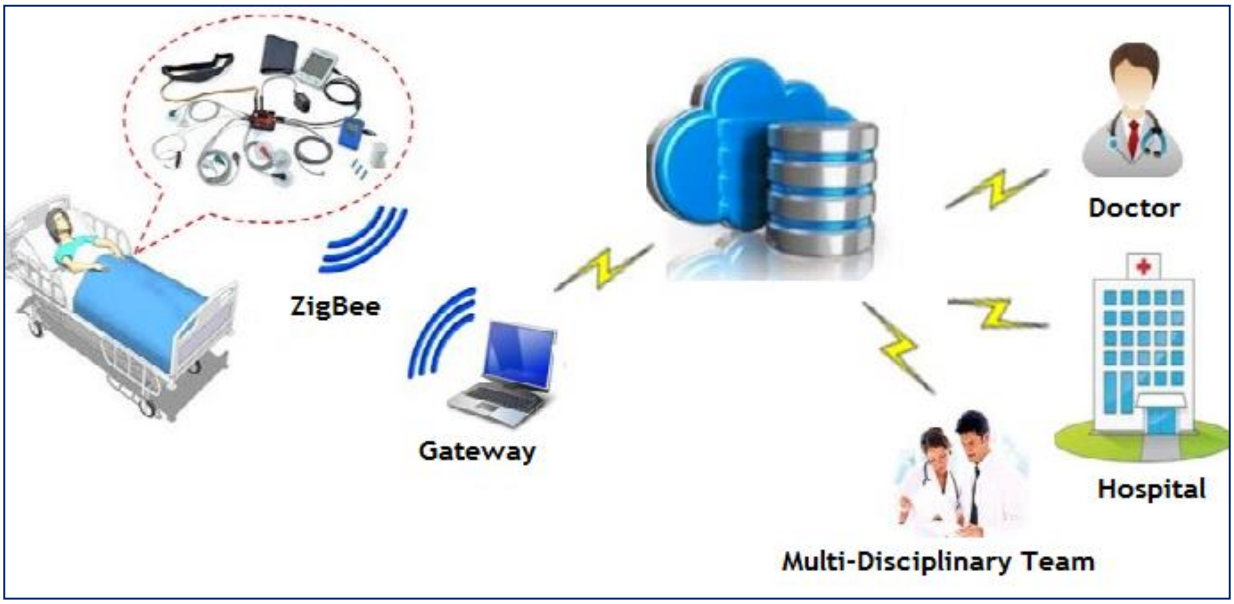


Figure 3.21 A developed patient monitoring system using ZigBee Technology. Source: (Hameed et al., 2016)

Another Chinese firm, Chengdu Cane Technology, developed a ZigBee-based device in 2016, for monitoring orderly's bodily conditions, with the added feature of automatically signalling for help upon breach of thresholds, so that timely assistance can be given (News et al., 2016). The application of this technology to fitness, with its integrated promotion of consistent fitness schedules for improved health, can lead to reduced demands for hospital care, with people leading healthier lives, and changes or anomalies in patients' health detected through continual or event monitoring (Alliance, 2009b).

3.9 Conclusion

This chapter presents a review of the up-to-date technologies used to track and monitor patients, staff, and assets in the healthcare industry, with the aim of supporting, choosing and implementing technologies suited to the needs and demands of Saudi Arabia, as outlined in Chapter Two.

The chapter provides an overview of indoors locating and real-time tracking technologies, discusses location-based services (LBS) and introduces the performance metrics of real-time location systems (RTLS), including accuracy, responsiveness, coverage, adaptivity, scalability, security, cost, and complexity. Next, the most important types of RTLS were covered, including GPS, infrared, ultrasound, and radio frequency, the last of which covers the remaining technologies: radio frequency identification (RFID), wireless local area network

(WLAN/Wi-Fi), Bluetooth, ZigBee, ultra-wideband (UWB), FM radio, Near-Field communication (NFC), and Hybrids.

Following an overview of Smart hospitals, the focus turned to how to use these technologies within hospitals for the best patient and asset flow, and for optimisation, purposes, both at a cross-sectional level and with system wide processes in mind. Our research found that Smart hospitals are being used to reduce average length of patient stay, increase patient safety and satisfaction, and improve financial performance and management systems. Our research found also clear evidence that introducing a new information technology systems into a hospital can be a financially daunting process. However, it was also clear that there are steps to follow to ensure that the technology selected is suitable for the environment, and that the organisation can handle the various burdens, both economical and operational.

The remainder of the chapter concentrated in comparing various RTLS in Smart hospitals, using the performance metrics outlined, and then using these comparisons to see how fairly to evaluate and select an appropriate system, considering the hospital's various circumstances. RFID and ZigBee emerged as the points of focus for such selection. Therefore, the final two sections concentrated fully into both RFID and ZigBee technologies, with the aim of integrating these two systems into a Smart hospital, so that their respective advantages over each other can be utilised appropriately. These two technologies have both been rapidly developing during the past two decades, but hospitals have not embraced them, due to various concerns, spanning from the financial to the technical aspects. The research for this chapter is intended to help clarifying the reasons why RFID and ZigBee have become the focus of the study. It is now clear that gathering a wider range of opinions is necessary in order to assess the need for adopting these technologies and the challenges of their implementation. A preliminary questionnaire is considered as the best way to gather such information, and Chapter 5 provides this questionnaire and analyses the data, therefore combining knowledge introduced in Chapters Two, Three and Four with current user requirements in Saudi Arabia.

Chapter 4 Development of a Holistic Framework for Real-time tracking and Monitoring in Saudi Healthcare

4.1. Introduction

The previous chapters provided an in-depth review of the current healthcare systems challenges, alongside Saudi Arabia's '*Vision*' for its own healthcare sector by 2030. Additionally, a detailed overview of relevant tracking and monitoring technologies determined RFID and ZigBee as the most promising for combined use in future implementations. Since their costs and benefits are currently unquantified, such a combined system must be analysed with respect to the environment of a healthcare institution, along with many other factors, before implementation can be considered. The 'environment' spans many factors, some of which include the human, business and organisational qualities of healthcare. Our analysis aims to determine which technology can help for the improvement of quality, safety and efficiency in healthcare. This chapter develops a framework for the implementation of a real-time tracking and monitoring system that can help Saudi Arabia institutions in the healthcare sector. Multiple perspectives will be described an analysed.

The most important concept within this chapter is to establish an adaptive process that considers all aspects of a healthcare institution, while ensuring the proposed new system is beneficial, necessary, and that it can be maintained. The first section is an introduction to the holistic framework developed throughout the chapter and implemented with a Health Information Technology Lifecycle Approach. This modified the four-stage lifecycle of Creswell et al. (2013) and adopted a five-stage lifecycle designed specifically by this researcher.

This framework is refined by Communities of Practice (CoPs), with an integration of the change-management literature for the guidance of designing a real-time tracking and monitoring system. Also, this holistic framework includes the selection of an appropriate system through CoP, continuously evaluating progress, and maintaining the system.

4.2. Holistic Framework

This chapter introduces the framework structure and the holistic method by which a new framework will be developed. Many frameworks exist, and aspects of their structures are utilised here for holistic development. Some are user acceptance models, and others consider the most relevant contexts to the specific technology. This section outlines the Information System Strategy Triangle (ISST) and the Human, Organisation and Technology-fit factors (HOT-fit) frameworks. Then a new theoretical framework is developed, based on the combination of the ISST and HOT-fit frameworks. This holistic framework integrates technology, organisational, human and business contexts, which are examined for its evaluation. In order to understand its development, this section also provides an overview of framework concepts, and of the holistic approach to the framework developed in this chapter. The two most relevant existing frameworks are discussed, for use in the design of a new holistic framework, refined by the analysis of similar healthcare information technology frameworks, and by the analysis of best fits for the Saudi healthcare environment.

4.2.1 Framework Concept

The framework concept has been widely used to approach information systems in various contexts (Ho & Atkins, 2006). Frameworks help guide research by improving communication amongst scholars, and providing the ability to share research. According to Jabareen (2009), a framework is defined as '*a systematic set of components fitted and joined together to support specific purposes*.' A conceptual framework interlinks concepts to '*provide a comprehensive understanding of a phenomenon or phenomena*'. These concepts support each other, explain their phenomena and collectively produce a philosophy specific to a framework. Every concept plays an integral role, provides an interpretative approach to reality, and provides understanding for the phenomena (Jabareen, 2009). The framework development follows this definition as it examines technology, organisational, human and business contexts for the purpose of integrating RFID and ZigBee technologies into healthcare institutions. Each of these contexts represents a concept in the framework that contributes to its philosophy in guiding analysis of the implementation.

The framework concept is used in this research because of its wide and standard acceptance by researchers in information systems (Ho & Atkins, 2006), and because of its flexibility in the order of use of each framework component (Jung et al., 2011). This ensures that new components can be added, based on the organisation's requirements.

4.2.2 Holistic Approach

As hospitals constitute a significant portion of the healthcare sector, and as these are complex and multi-faceted organisations, any framework that intends to implement a new information system must approach all perspectives and factors that affect this kind of organisation. A holistic approach considers the interdependencies of various perspectives, such as technology, human and organisational. This addresses the problem, put forward by Van Gemert-Pijnen et al. (2011), that these interdependencies are often disregarded and that new technologies result in low impact in practice (van Gemert-Pijnen et al., 2011). This holistic approach utilises concepts from several existing theoretical frameworks, which the researcher identified as being relevant to tracking technology systems, and two frameworks were selected from which to build a new one.

4.2.3 Review of Related Theoretical Frameworks/Models

Dozens of possible frameworks and models could be applied to the application of tracking and monitoring technologies, but the use of too many frameworks or merely a single framework has the potential for being far too complex or too simple. Some of the frameworks considered are detailed here, with reasons for their rejection made clear. The Technology-Organisation-Environment (TOE) framework uses two contexts that were accepted for the holistic framework, but 'Environment' was discarded. The environmental context considers external elements affecting system adoption, such as competitive forces and governmental regulation (Baker, 2012). Although not the exact same as the business context explained in the holistic framework, the environmental context has enough overlap to be discarded as they both consider external factors and since the financial factors often consider competitive forces instinctively.

The remaining frameworks should be included in the paragraph above and could likely all be taken from Majid:

- UTAUT
- TAM
- DOI

For the integration of two specific technologies (RFID and ZigBee), however, the focus was narrowed to the use of only two frameworks. These two frameworks are the Information System Strategy Triangle (ISST), and the Human, Organisation and Technology-fit factors

(HOT-fit). Both frameworks possess shared traits, which will be examined in the context of healthcare implementation, to illustrate the need to combine two frameworks. The result is aimed at supporting the decision process in healthcare organisations by covering all perspectives. This combined framework ultimately works because it can adapt to changing conditions (Rusu & El Mekawy, 2011).

4.2.3.1 Information System Strategy Triangle (ISST)

The Information Systems Strategy Triangle (ISST) was developed by Pearlson and Saunders (2001) for the purpose of taking business concepts and organisational strategies into better consideration, in the context of technological innovation (Pearlson & Saunders, 2010). As shown in Figure 4.1, this framework uses three different strategies as the points of a triangle. This illustrates the relationships among the three strategies, the ways in which they impact on each other, and emphasises the importance of alignment between these three strategic perspectives (Rusu & El Mekawy, 2011). In this framework, Business Strategy is the primary driver, as it affects all other perspectives. The Organisation and the Information System (Technology) can help define the business goals and objectives. Organisational Strategy refers to the outline by which an organisation designs, plans, performs and controls its functions for the successful implementation of its business strategies and aims. The Information Systems (Technology) Strategy is for using Information Technology and Services to achieve the business aims (Rusu, 2011), and is affected by the other strategies shown in the triangle (Pearlson & Saunders, 2010).

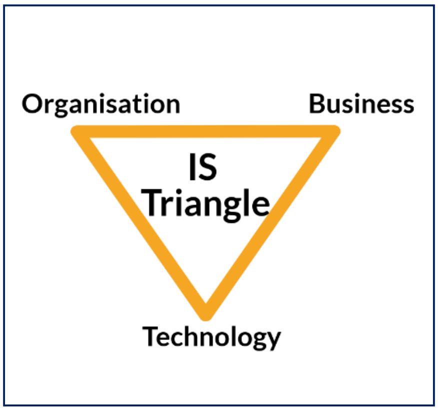


Figure 4.1 Information System Strategy Triangle (ISST) by Pearlson & Saunders, 2010

In healthcare, the implementation of new information systems requires heavy installation of infrastructure, which can quickly become costly. It is therefore important that business strategy remain in focus while considering technologies that affect an entire organisation (Farid et al., 2013). Many costs and benefits linked to RFID and ZigBee systems were summarised in Chapter 3, as part of the considerations necessary to any framework. Some of the benefits, such as robustness, allow the system to last longer. Additionally, Cao et al. (2014) revealed, in a survey of healthcare practitioners, that competition is not a foundation for the adoption of innovative technologies; but competition in healthcare does exist in a different form. Physicians and nurses compete against benchmarks designated by management and based on performance metrics. These benchmarks can be defined by a variety of metrics, as demonstrated by the 18 strategic objectives listed in Saudi Vision 2030 (2016) specifically for healthcare, or by the 400 benchmark indicators given for the entire country. Business strategy is therefore a logical place to begin the analysis for healthcare implementation, and ISST is given priority in this research, as supported by the literature search. This research applies the business concepts of ISST for decision-making processes involving information systems, in coordination with the framework discussed in the next section.

4.2.3.2 Human, Organisation and Technology-fit (HOT-fit) Framework

The other framework considered for this holistic approach is the Human, Organisation and Technology-fit (HOT-fit) framework – see Figure 4.2. Introduced by Yusof et al. (2008), HOT-fit was designed specifically as an evaluation framework for health information systems (Yusof et al., 2008). The technological factors completely align with the existing factors described for ISST, and organisational factors similarly possess heavy overlap and therefore require no additional discussion. Human factors include those concerning individuals within the organisation, such as user acceptance, technical complexity, privacy, and so on (Lian et al., 2014; Yusof et al., 2008).

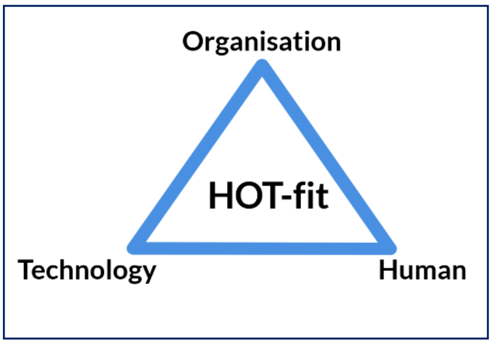


Figure 4.2 Human, Organisation and Technology-fit (HOT-fit) Framework by Yusof et al. (2008)

The overlap between HOT-fit and ISST means that the unique contexts are human and business contexts, respectively. These contexts have been identified from the comprehensive literature search, as apt to holistically provide a framework upon which to make decisions on innovation in information systems (Shrestha et al., 2016). The resulting holistic framework will be discussed in the following section for the use of real-time tracking and monitoring technologies to support stakeholders in Saudi healthcare.

4.2.4 The Holistic Framework for Real-time tracking and Monitoring in Saudi Healthcare

Researchers have developed holistic frameworks in the context of healthcare that have resulted in various combinations of the contexts explored so far, including (but not limited to) the human context, organisational context, technological context and business context (Lluch, 2011; Van Gemert-Pijnen et al., 2011). The stakeholders of an integrated RFID and ZigBee tracking and monitoring system in healthcare can be classified as the patients (human), nursing staff and physicians (human), and management (organisation). Additionally, business has been identified by numerous case studies (Lai et al., 2014) as a key factor in the decision makers' acceptance of a new tracking and monitoring system. Technological factors are of obvious importance, as these new systems require infrastructure across the institution and are built on technological innovations. As a summary of this holistic view, the four contexts are here described for clarity and future elaboration.

- Technology context: The selected technologies, technical issues and requirements affecting the decision to implement RTLS. This context was chosen so that the many factors of the technologies, delineated by an analysis of their costs and benefits, could be understood before adoption and since technology is the underlying foundation of the tracking and monitoring system.
- Organisational context: The internal factors of an organisation and factors under its control. This context was chosen due to the significance of the competence of management and the relationship of management with their staff as they relate to the rate of success for technology adoption.
- Human context: The factors related to staff's IT competency, and user acceptance by both patients and hospitals personnel. This context was chosen for the critical influence that individuals can wield within the setting of a healthcare organisation such that a single person's negative attitudes can spread and cause the technology to fail. IT

competency also dictates staff's ability to properly use the technology, so proper training can mitigate the potential downside at the individual level.

- Business context: The issues related to business matters and financial cost in implementing RTLS. This context was chosen due to the potentially significant costs associated with systemwide technology implementation in a healthcare organisation, while also stressing the ability of the new technology to reduce future costs and increase future benefits such as efficiency and patient care.

Figure 4.3 presents the holistic framework for real-time tracking and monitoring. The framework focuses on four main factors, which are: business, organisation, technology, and human. These factors are within the framework that was utilised from the combination of two frameworks: Information System Strategy Triangle (ISST) and Human, Organisation and Technology-fit factors (HOT-fit) framework.

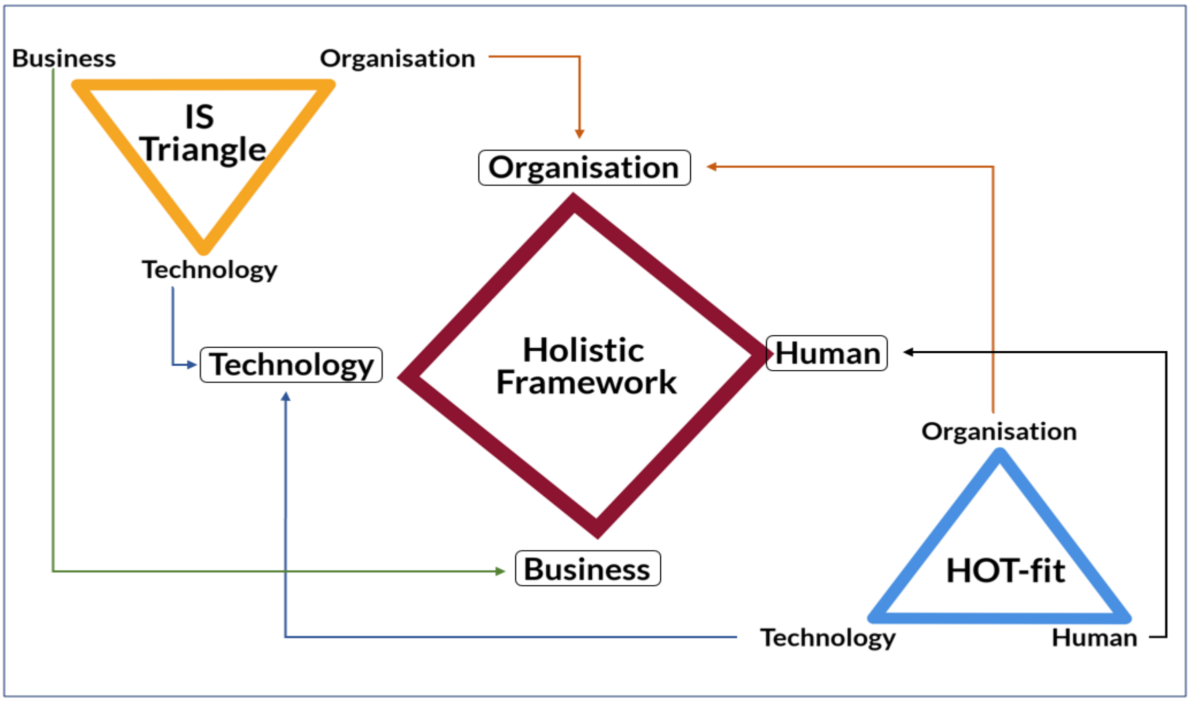


Figure 4.3 A Holistic Framework, Business, Organisation, Technology, and Human

The framework will help healthcare organisations in their real-time tracking and monitoring decision-making adoption process, by evaluating the factors affecting the adoption process. The purpose of the holistic framework is to help healthcare organisations to provide better healthcare services with lower costs and high standards. The framework is developed consulting the literature covering, from multiple perspectives, the critical factors that affect the decision on the adoption of real-time tracking and monitoring.

Table 4.1 summarises the factors and contexts identified in empirical studies of tracking and monitoring adoption published in peer-reviewed journals.

Table 4.1 Empirical studies of tracking and monitoring adoption published in peer-reviewed journals

Theory	Factors	Sector	References
ISST	Design, Robustness, Security, Training	Hospitals	Lian (2017)
TOE	Reliability, Top Management Support, Design , Data Accuracy	Higher Educational institutes	Tashkandi & Al-Jabri (2015)
DOI & IPV	Maintenance, Accuracy, User Acceptance, Integration	Manufacturing and retail industries	Wu et al. (2013)
HOT-fit	Data Accuracy, Energy Consumption , Design , Cost, Top Manager Support, Reliability	Hospitals	(Jaschinski & Allouch, 2015)
DOI & TOE	Reliability, Robustness , Technology readiness, Top Management Support, Maintenance, Regulatory Support, Concerns, Cost savings	Service sector and manufacturing	Oliveira et al. (2014)
ISST	Reliability, Top management support, Innovativeness, Data Accuracy , Design	SME	Alshamaila et al. (2013)
HOT-fit	Integration, Usability, Energy Consumption, User Acceptance,	Hospitals	(Jacobsson et al., 2016)

The framework and its four main factors, together with sub-factors, are presented in Figure 4.4. These factors were taken from Table 4.1 and adjusted accordingly based on overlaps or irrelevance. For instance, ‘data accuracy’ was replaced with ‘accuracy’ and ‘regulatory support’ was assumed to be contained within the ‘soft financial analysis.’ Theories beyond the two accepted frameworks (ISST and HOT-fit) were used for generating the initial list of factors since the individual factors have the potential to share certain traits with other contexts. The similarity between TOE and ISST can be seen, for example, in all factors mentioned with ISST adding innovativeness, security and training to its list. The factors were first divided based on context, then similarities allowed some factors to be discarded such that the organisational, human and business contexts are each simplified to two factors. The following sections discuss the factors and their implications.

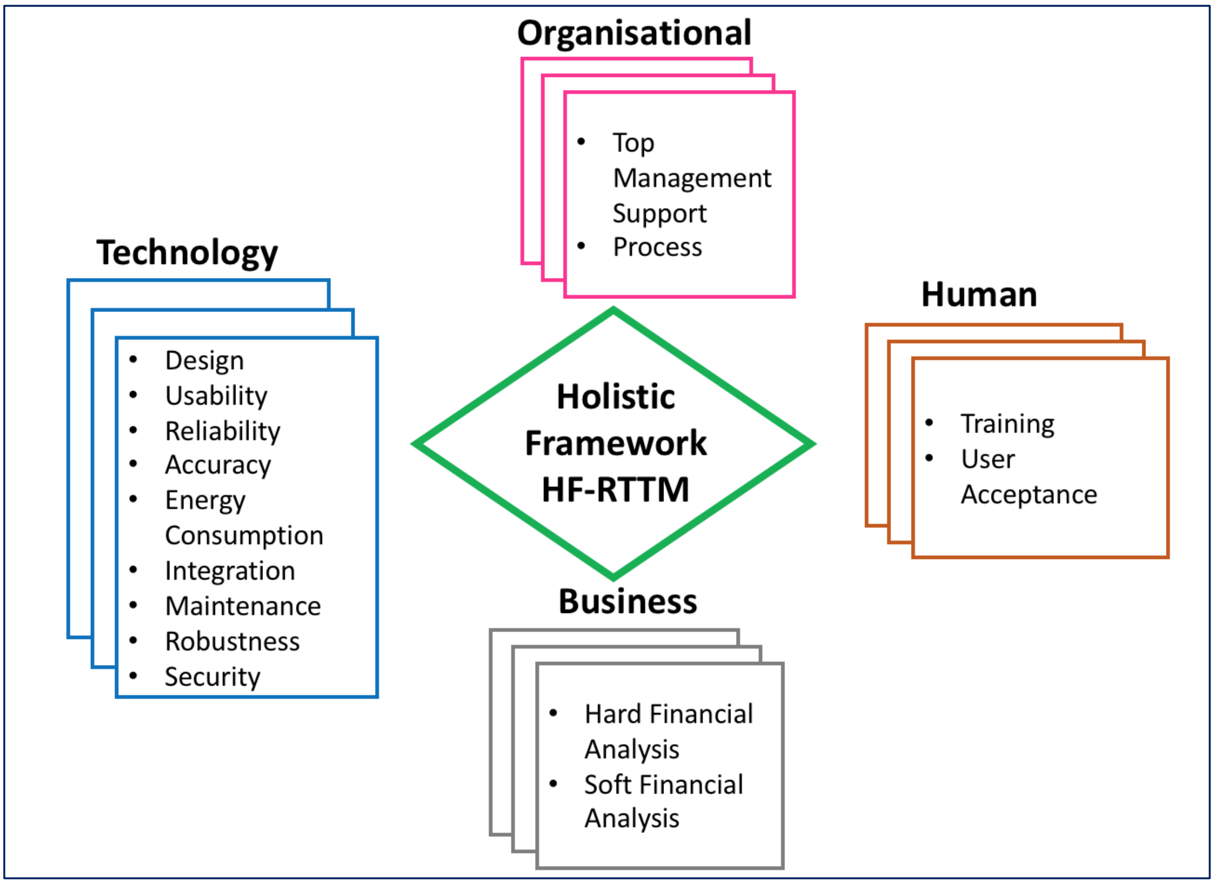


Figure 4.4 The Holistic Framework for Real-time tracking and Monitoring in Saudi Healthcare.

4.2.4.1 Technology Context

Some of the technological metrics include design, usability, integration, accuracy and reliability (Farid et al., 2013). In translating these metrics into relevant factors for a healthcare organisation to consider, some must be altered, combined, or supplemented with additional aspects. As this decision has a technological foundation, the underlying technology has the greatest number of factors. They can best be categorised into compatibility factors and performance factors. Compatibility factors answer the question: “How well does this new system fit with the current system?”, while performance factors answer the question: “How good is this system?” Using compatibility to check for best fit, while using performance to check for relative advantage, results in the best analysis of the technological aspect of IT. Integration with the existing IT infrastructure is a key tactical factor (Yao et al., 2012), and compatibility is vital. The entire list of technology factors extends beyond the metrics, including system integration, robustness, security and design. The factors, as outlined, can be compared qualitatively between technologies, as they relate to compatibility with existing infrastructure. This includes ensuring that the frequency of a new system does not disrupt current systems, and likewise that existing frequencies will not hamper the performance of a new system.

Technical advantages of RFID have been given as the improved delivery of healthcare services, including: the ability to control processes more efficiently, greater capacity to reduce paperwork and manual labour, increasing tele-health capabilities; and the relative advantage of RFID technologically, such as its better durability, its functional superiority over other technologies, such as barcodes, and its ability to identify thousands of tags per second run (Abijith & Wamba, 2012; Vilamovska et al., 2009). Technical advantages of ZigBee have been given as: its extremely low power consumption (Liu & Sahandi, 2009), simple installation and low cost, and capability of a high number of node connections (Jiang et al., 2017; Jihong, 2011). An integrated tracking and monitoring system uses these advantages to create an intelligently “diversified portfolio” of technologies. ZigBee counters the high initial investment and complexity of RFID with its low cost and simple installation, while both improve the return on investment in the long run (Abijith & Wamba, 2012; Vilamovska et al., 2009). The relative advantage of an integrated RFID/ZigBee system on each standalone technology is readily apparent by case studies in the literature. Therefore, aligning compatibility with the existing infrastructure is the key point of concern, given the various qualities mentioned concerning real-time location systems (Vilamovska et al., 2009).

The security of the system can be associated with legal compliance and user acceptance, as trust by patients in the healthcare system, and ability for hospital staff to maintain patient confidentiality are key factors in the system’s success (Gagnon et al., 2012). Devices must similarly pass regulations on security, such as protecting data against theft and unwanted access (Gagnon et al., 2012). Security also refers to the ability and requirement of technology to increase the safety of patients (Sheikh et al., 2011) through alerts often sent to nursing staff.

4.2.4.2 Organisational Context

In the selection process of an appropriate real-time tracking and monitoring, the internal factors of an organisation include its internal process and top management support and approval (Jong-Deuk, 2007; Potančok & Voříšek, 2016). As stated in the previous Section 4.2.4.1, a new HIT system must align sufficiently with the top management support, or the results for user acceptance can nullify any potential technological benefits (Yao et al., 2012). Multiple case studies have shown that organisation administration is a significant factor in adoption of health information technology (Hikmet et al., 2008; Potančok & Voříšek, 2016; Wang et al., 2014). Organisational resistance is another significant factor, with the collective level of approval as a determinant in the success of the system. Collaboration of participants in the system, especially during the training process, has been shown to reduce effectively organisational resistance (Gagnon et al., 2012). Therefore, support by top management is essential before acceptance of the system can occur. The characteristics of an organisation's leaders, though often unable to be categorised besides being positive or negative, significantly affect the adoption decision (Lee & Shim, 2007). An organisation's maturity is also relevant, as it may be associated with levels or complexity of existing infrastructure, staff training and competency in technology, and budget (Potančok & Voříšek, 2016). The organisation's structure can determine permissible forms of sourcing, as well as staff adaptability to new processes associated with the implemented system (Potančok & Voříšek, 2016).

Almalki et al. (2011) call for the privatisation of Saudi hospitals has begun to be answered, with the privatisation of 17 hospitals underway, with hopes of improving these hospitals' efficiency by 25% by 2021 (AB, 2018). Proper utilisation of these hospitals will allow the proliferation of data within the Saudi context, for an expanded field of study for future e-health developments. Beyond the privatised organisational structure of Saudi healthcare institutions, the current infrastructure is a critical factor for health information on technology implementation over the course of the next decade, as it is believed to be strained by growing demand nationwide (Lingawi et al., 2014). The present lag in technological infrastructure means that new information technology systems will typically be integrated with existing processes rather than existing technology, especially for hospitals that have not yet adopted electronic medical records (Hasanain et al., 2015).

4.2.4.3 Human Context

The factors related to the people affected by a new health information technology system include user acceptance, and training. The interface through which both staff and patients interact with the system is important, as it often determines the amount of resistance encountered by the system (Yusof et al., 2008).

User acceptance can be influenced by the current technical competence of system participants, the fit between the user and the organisation, the attention given to training, the availability of future and ongoing technical support, and the design of the system and devices (Gagnon et al., 2012; Yusof et al., 2008). For this reason, emphasis is given later in this chapter to training healthcare personnel, as studies have shown negative perceptions of new systems when inadequate training is undertaken (Gagnon et al., 2012). A thorough understanding of the technical competency of the various groups working in the organisation could influence management to adopt a more complex system, as the belief in one's own competency is correlated with individual ability to adapt (Gagnon et al., 2012). The human context therefore requires devoting time, effort and resources to ensure the successful implementation by emphasising the training and user acceptance.

In Saudi Arabia, failure of health information technology implementation is frequently due to a lack of technical and computer skills of hospital staff (Khalifa, 2013). This is a significant barrier to the adoption of information systems, and it is given much attention in this research. Human barriers were ranked as the most influential factor in these failures (Khalifa, 2013), which is why they deserve a large consideration in the planning phase. Adequate time, effort, persistence and financial resources must be devoted to the training of staff, as user technical ability tends to lag in Saudi Arabia (Altuwaijri, 2008). Furthermore, there has been a persistent shortage of local healthcare professionals in Saudi Arabia, exacerbated by the high number of expatriates, often on short term contracts, that leads to high rates of turnover (Almalki et al., 2011). There have been multiple calls for plans and strategies to improve healthcare, as directed by the Ministry of Health (MoH) (Almalki et al., 2011, Khalifa, 2013), addressed by the Saudi Vision 2030, and which this research seeks to help achieve.

4.2.4.4 Business Context

The issues related to financial cost for the implementation of a health information technology system can be divided into hard financial costs and soft financial costs. Hard financial costs are defined as the labour and materials devoted specifically to the project, while soft financial costs are all other indirect expenses, such as planning costs. As RFID/ZigBee have been considered a promising investment, its cost is a key consideration (Wang et al., 2006; Yazici, 2014). Financial cost was a primary reason deterring hospitals in Taiwan from adopting RFID without a pilot study (Lai et al., 2014). Research has shown that these concerns are unsubstantiated for RFID, due to its ultimate Return on Investment (ROI). In the long run, hospitals have experienced considerable time savings by identifying empty beds more than 20 minutes earlier than traditionally way. This allows for faster patient turnover, better hospital utilisation; and work reduction by nursing staff, as the new system reduces their daily activities by 50% (Anand et al., 2013). Consequently, this leads to large financial savings that make the initial investment insignificant, as long as it can be funded (Krainer, 2014). Additionally, financial gains must be achieved from various channels, such as through savings in medical assets that are no longer lost or misplaced, and by savings through the avoidance of product expiration and lost revenue. A four-month case study by Abijith and Wamba (2012) for an acute care facility, Southwest Medical Center in Oklahoma, U.S.A., found that savings amounted to $111,500 for assets that would have otherwise been lost or misplaced, $223,000 retained due to inventory management reducing product expiration, and $614,600 saved from avoided lost revenue. Savings based on the number of beds in a hospital are estimated at $1 million annually for a 500-bed hospital (Abijith & Wamba, 2012), which when extrapolated linearly for a $200,000 infrastructure cost for a 200-bed hospital would indicate a $500,000 investment for a 500-bed hospital (Vilamovska et al., 2009).

This cost would then be recovered in roughly 6 months. As RFID tags are estimated to last between two and six years, even the low estimates provide enough time to recover the initial investment (Farid et al., 2013). This information was based on RFID tag cost estimate of $0.15 for tags with a 96-bit EPC inlay embedded with a thermal transfer label (RFID Journal). A larger hospital, however, may be able to take advantage of volume discounts, so that price per square foot would decreases as the number of hospital beds increases. Given the overall ROI, however, once the initial investment hurdle is passed, the organisation should understand the system-wide financial benefits reaped by the implementation of RFID and ZigBee.

Much of the Saudi healthcare system is funded by the MOH, which has recently received a greater portion of the government's annual budget than in previous decades. The portion of healthcare spending hovered around 6% of the national expenditure until the introduction of Saudi Vision 2030, which allocates $10 billion to the MOH, from the $100 billion devoted to the National Transformation Program's (NTP, 2016). This 10% of the national budget is also more focused on restructuring of primary care ($1.3 billion) and electronic health initiatives ($2.4 billion). MoH estimates that around 21% of all Saudi hospital services will be provided by private institutions; these institutions are monitored by the MOH and can be advised by the MOH for achieving the government's health objectives. Privatised and fee-based healthcare institutions have much more financial freedom in adopting technologies that have a higher expected return on investment. Similarly, it is the responsibility of all hospitals to attract greater investment from the private sector to facilitate the adoption of e-health and other technology-related advancements.

4.3. Real-time tracking and Monitoring Adoption Strategy

Approaches to IT systems development are classified into a variety of frameworks. They can be linear, interactive, or a combination thereof; and are defined by the systems development life cycle (SDLC), which is a term used for information systems, to describe a process for planning, creating, testing and implementing IT (Centers for Medicare & Medicaid Services, 2008). In this study, the focus is on a lifecycle approach that follows four lifecycle stages, divided into several considerations that further divide the stages into smaller steps, and focus on processes over time (Cresswell et al. 2013). Many of the factors brought forward in factor models are identified here for consideration, such as those under the groupings of technology, business, organisational and human.

The process adapted for use in this research consists of four lifecycle stages, as provided by Cresswell et al. (2013), which are designated by their '*ten key considerations for the successful implementation of health information technology*'. Figure 4.5 shows the ten key considerations in the lifecycle of health information technology, and the four lifecycle stages which will be used as a foundation for the framework adoption strategy. The adoption strategy is as follows:

1. **Establishing the need for change**

The best way, identified by Cresswell et al. (2013), for establishing a need for change is to thoroughly map existing processes. This can help identify existing problems for all parties affected by a new system, and ideally leads to a long-term strategic vision. Important to this discussion and analysis is also the assessment of how existing technology in an organisation can support the goals identified in the strategic vision (Cresswell et al., 2013).

2. **Selecting a system**

After the need for change has been established, it is first necessary to build consensus among the various groups of stakeholders, such as physicians, nurses, management, and administrative staff. Then, the decision makers must consider all available options, keeping in mind systems that are affordable for the institution and that meet the institution's needs (Cresswell et al., 2013).

3. **Planning (which includes the implementation strategy, infrastructure, training and human aspects)**

Appropriate planning requires the development of a thorough implementation strategy, with consideration for: flexibility, prioritisation of functionality, and maintaining open communication channels between management and users. The institution's infrastructure is considered here, both for integration with the institution's existing technology, and for ensuring that healthcare personnel and patients will be able to adapt to the changes. This leads to the training aspect, which requires time, effort, and financial resources to be devoted to the continuous technical abilities of staff and patients (Stokes, 2013).

4. **Maintenance and evaluation**

Lastly, the system must be maintained, as existing technology improves, through persistent and periodic upkeep of staff technical knowledge, infrastructure and organisational strategy. Cresswell et al. (2013) recommend that progress be evaluated continuously, something facilitated by the intervention of information technology, but still demanding attention and sufficient resources.

The ten key considerations have been adapted to fit the inclusion of change-management in a Saudi healthcare and Communities of practice (CoPs), which has been formed by the researcher to facilitate the creation of a developed approach for the improvement of the this research. The modified approach provides the following structure:

1. Establish the need for change using the principles of change-management by establishing a CoP.
2. Consider Saudi healthcare options with the CoP
3. Select a system with the CoP

4. Plan with the CoP
5. Maintain and evaluate the system with the CoP

The modified version of the summary of the lifecycle stages of health information technology and the ten key considerations is outlined in Figure 4.5.

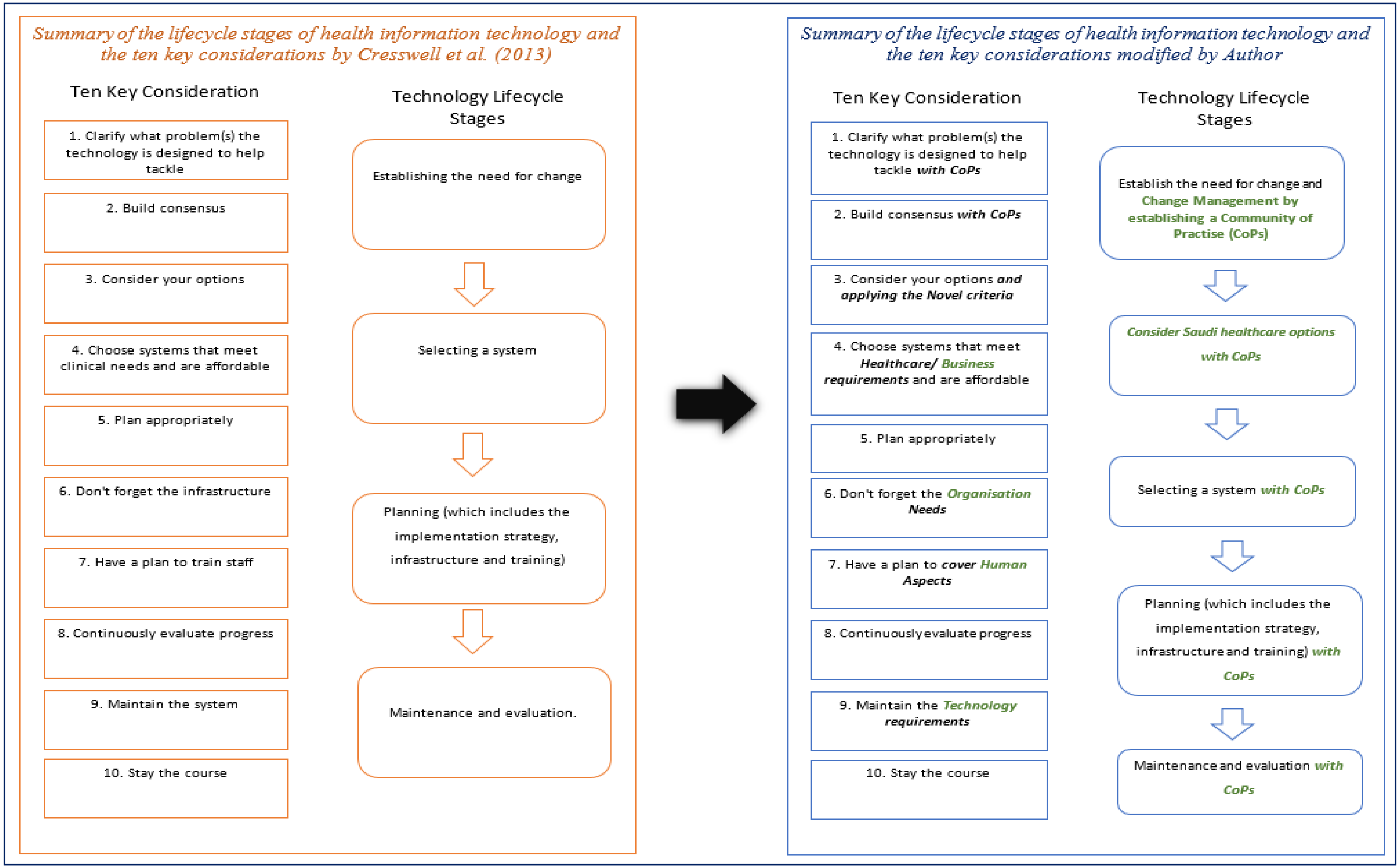


Figure 4.5 Summary of the lifecycle stages of health information technology and the ten key considerations by Cresswell et al. (2013) and the modified version by the author

4.4. Communities of practice (CoPs)

In order to determine the most appropriate technology that can improve hospital efficiency and effectiveness, and meet the current needs, the performance parameters need to be matched with the user requirements (Mahapatra, 2015). One vehicle in existence to solve this problem is the Community of practice (CoP).

4.4.1 Definition of CoPs

A CoP is a '*group of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly*' (Agrifoglio, 2015; Wenger, 2015). The term was first used by Etienne Wenger (1991) to describe the nature of learning via practise and participation (Panatik et al., 2014). CoPs are formed by people who learn together within a shared domain, such as a set of surgeons exploring new techniques. The concept has existed for as long as people have shared their knowledge and experiences, often through storytelling (Agrifoglio, 2015; Wenger, 2015). Organisations and industries often form CoPs naturally, for as little as a single shared goal. People join CoPs for a variety of reasons, usually centred around education, professional issues and hobbies, and to solve problems together. The CoP is the vehicle by which an individual can share a unique experience with other members for their ultimate benefit (Agrifoglio, 2015). Researchers outlined that a small number of participants (between 5 and 10) in the CoPs resulted in better interaction among the members, as well as the better exchange of ideas, knowledge sharing, and mutual engagement (Wenger, 2015). The CoP in this research formed from 8 participants.

CoPs are composed of three elements: the domain, the community, and the practice, as shown in Figure 4.6. The development of both relationships and knowledge is a primary purpose of CoPs, either formally or informally. This leads to new practices put into place and experiences generated, followed by its integration into the domain of knowledge through something later explored with internalisation in the SECI model (Dubberly & Evenson, 2011; Wenger, 2015). According to Wenger (2015), a CoP goes beyond a mere club of friends or network of connections; but rather it possesses an identity defined by the group's shared domain. Even though membership implies commitment to the domain, someone may belong to the same network as others in the CoP and be unaware of this. The community of a CoP requires a group of people to actively engage with each other and share information. This does not require daily interaction, but the CoP facilitates discussion and the growth of its members. The practice means that the CoP's members are practitioners, who develop a shared repertoire of resource. The definition of 'practice' is as follows: *'A set of frameworks, ideals, tools, information, styles, language, stories and documents'* (Wenger et al., 2002 in Pyrko et al., 2017; Wenger, 2015). The degree of formality present in a CoP can vary wildly, with some of these sets of knowledge being utilised much more than in other CoPs (Pyrko, 2017). Nevertheless, the combination of these three elements constitutes a CoP, whether structured or free-flowing (Wenger, 2015). Some of the activities CoPs engage in to develop their practice are: problem solving, requests for information, experience seeking, reusing assets, coordination and synergy, building an argument, growing confidence, discussing developments, documenting projects, visits, mapping knowledge, and identifying gaps (Wenger, 2015). Among the examples given by Wenger (2015), several involve aspects of change-management. Therefore, it is logical to use CoPs to help in selecting an appropriate system in healthcare, following the steps outlined in the section on change-management.

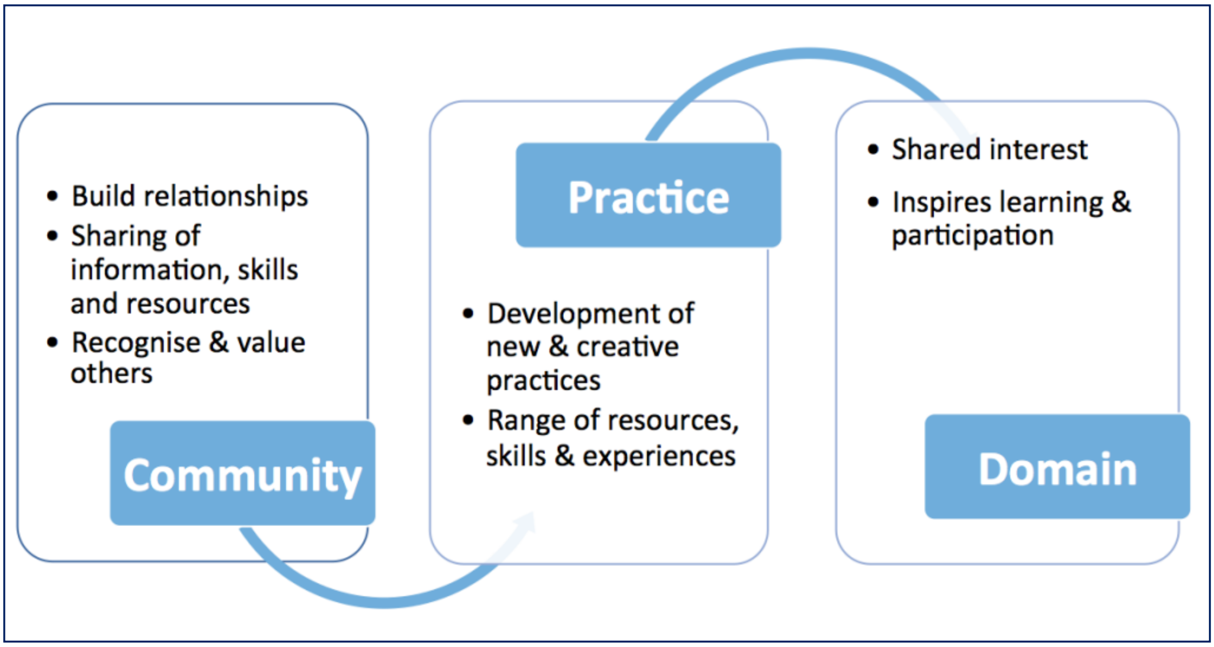


Figure 4.6 Community of practice characteristics. Source: http://www.disabilityjustice.edu.au

Saudi Arabia is a country with inherent cultural systems in place that can facilitate knowledge sharing, though this is not always practised (Almuayqil et al., 2015; Sawsan & Lyn, 2015). CoPs have a potential in Saudi Arabia, to assist for the benefit of the healthcare sector.

4.4.2 Role of CoPs for the Holistic Framework

Researchers as outlined previously suggested a small number of participants (between 5 and 10) to develop the CoP which would result in better interaction among the members (Wenger, 2015). For this research purposes, the researcher formed a multidisciplinary group qualifying as what has been defined as a CoP. This group includes members with a variety of backgrounds, such as medicine, nursing, pharmacy, bio-medical, administration, IT etc. (8 participants). This group had met on a regular basis throughout this research's stages to discuss issues and challenges, to benefit from their experiences and to guide this research to achieve its purposes.

In regard to evaluating and selecting an appropriate system, the CoP utilised for this research performed the following:

1. Reviewed the existing Saudi Arabian healthcare challenges and barriers.
2. Discussed the potential benefits and expected challenges of adopting a RTLS in healthcare.
3. Identified hospital areas where RTLS is required and beneficial.
4. Reviewed and compared different RTLS technologies and applications, and their advantages and disadvantages.
5. Identified the most important hospitals' requirements.
6. Developed novel criteria for choosing the appropriate technologies that meet a hospital's needs, standards, and expectations in achieving the goals set.

The existing literature on the frameworks utilised for selection of the human, organisational, technology and business contexts was the basis for the initial identification of factors for the holistic framework as outlined in Figure 4.4. As the members of the CoP came into contact regularly with healthcare organisation settings, they were naturally fit to judge the user requirements that translate into the factors within the four contexts chosen. Once presented with this list by the researcher, the CoP used its combined knowledge set and the discussions and analysis summarised above to produce the novel criteria in point (6) above and the refinement of the holistic framework as detailed in section 4.5.

Based on the discussions and meetings as summarised above, and by utilising the steps in the context of Saudi Arabian healthcare, the researcher and the CoP agreed that the RFID and

ZigBee combination creates the most appropriate system to fulfil the project's purposes. RFID and ZigBee can both be used for tracking certain objects. RFID will provide faster scanning speed for large volumes of tags, and ZigBee can provide almost unlimited network scale with lower output power, which is a significant benefit for healthcare applications particularly in tracking and monitoring in a people-oriented environment (Hui et al., 2014). Using such emerging sensor technologies, which automatically scan and use non-contact and non-intervention for tracking objects and users, will allow for the transfer of real-time information and the visualisation of objects such as patients, staff and equipment location throughout the hospital. This will improve the management information systems, and provide more effective decision support systems (Alharbe et al., 2015). Moreover, those technologies are cost-effective compared to other technologies.

The purpose of CoPs in this context is to continue developing this model, so that more criteria can be utilised, and can become more refined. Additionally, CoPs can be conferred with, when considering unique new applications of technology in healthcare, with experience expanding constantly and better solutions found with each new implementation of RTLS.

4.4.3 Establishing the Need for Change

Prior to any implementation consideration of a new information technology system in healthcare, the problem must be identified for anything new that would resolve it. The first step in the lifecycle approach is therefore to establish the need for change. This step aims to placate the tendency for divisive assumptions to arise, and for an incoherent strategy to form. The best way, identified by Cresswell et al. (2013 to establish a need for change, is to thoroughly map the existing processes. This can help identify existing problems for all parties affected by a new system, and ideally leads to a long-term strategic vision (i.e., Saudi Arabia's Vision 2030, for a National Case). Change should take unique circumstances into account and, once its need is established, build consensus for the strategic vision among both practitioners and administrators of healthcare. This process is the underlying principle of change-management. Through preparation and aligned goals, change-management aims to provide a foundation for an adaptive framework, by which to select and implement the best information technology system to help healthcare providers to control increased costs with current growing demand and regular growth – see Figure 4.7.

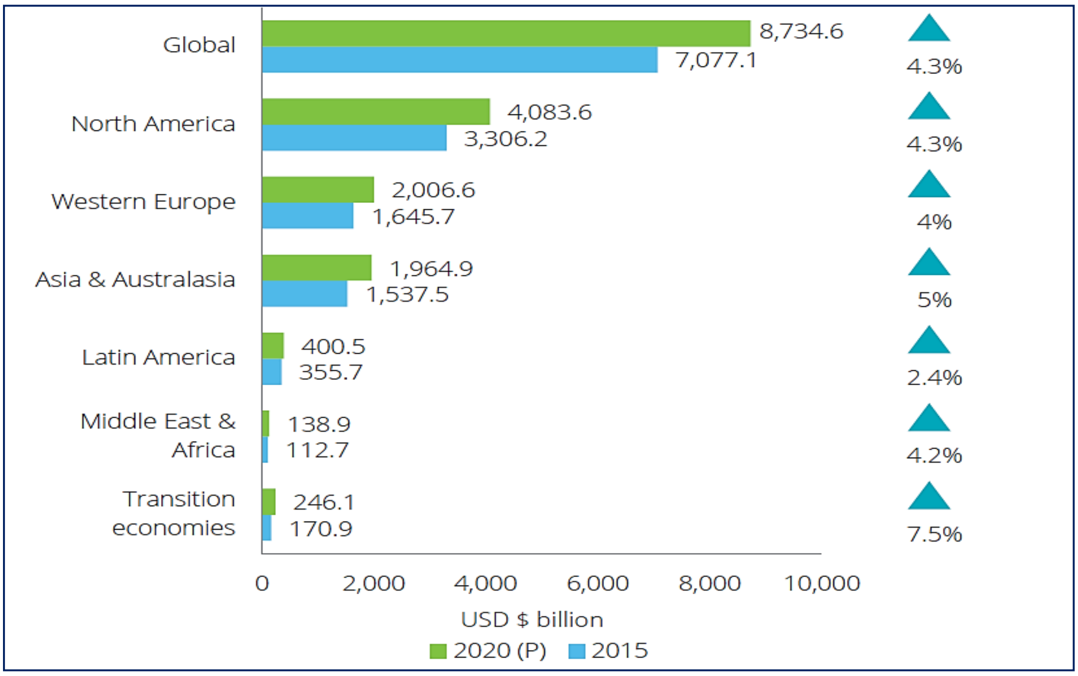


Figure 4.7 Healthcare spending, 2015–2020. Source: (Deloitte, 2017)

It is obvious that healthcare costs are increasing annually while some critical healthcare performances indicators show the opposite. As an example, recent statistics in the UK, shows that NHS providers are increasingly struggling to keep up with growing demand for patient treatments. Between 2012/13 and 2015/16, purchase by NHS of healthcare from private healthcare providers increased by almost 60%, increasing at an average rate of 20% per year as shown in Figure 4.8, as healthcare providers tried to keep pace with demand.

Figure 4.8 NHS purchase from non-NHS bodies, 2012/13 and 2015/16. Source: Department of health, UK

Despite this, new referrals are stacking up faster than hospitals can treat them, with two inevitable results. Firstly, waiting lists are getting longer: the total number of patients waiting for treatment has risen from 2.48 million in 2012 to 3.5 million in 2016 as shown in Figure 4.9. Secondly, waiting times are increasing. Providers are expected to treat patients within 18 weeks of referral, with a national target that at least 92% of patients on the list at the end of every month should have been waiting less than that time. However, by the end of 2015/16, 91.5% of patients had waited less than 18 weeks compared to 94.1% at the beginning of 2012/13.

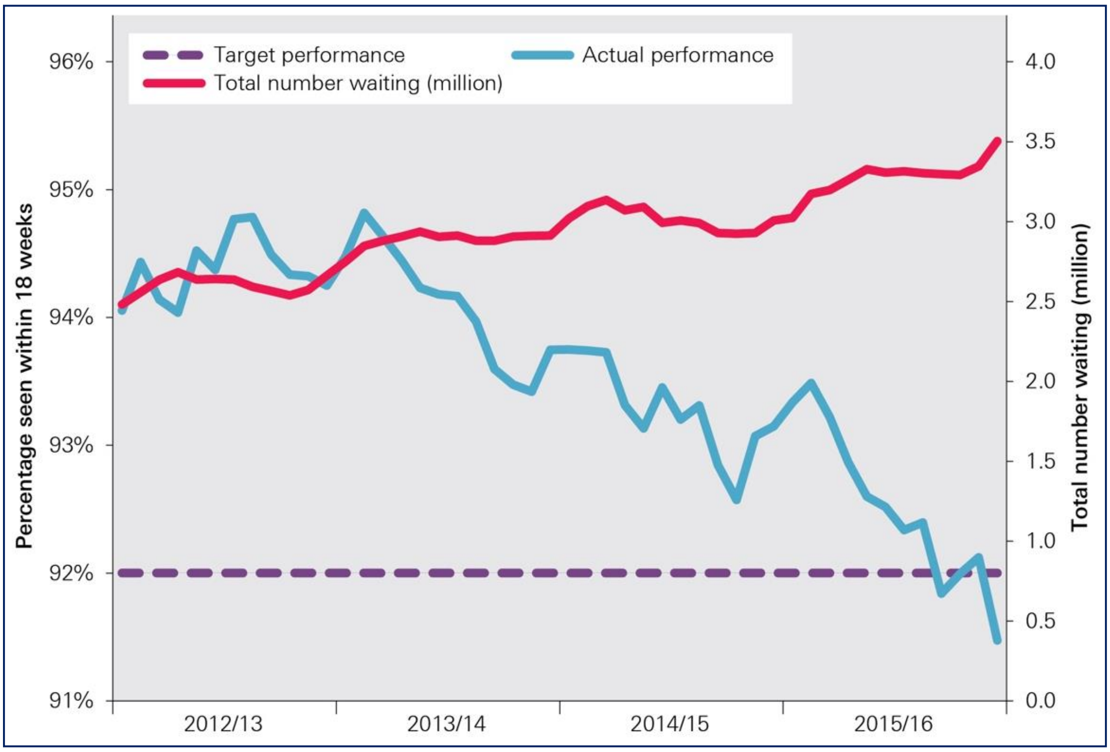


Figure 4.9 Performance against referral to treatment waiting times, and total number waiting (million), 2012/13-2015/16. Source: (NHS, 2016)

Waiting time is one of the current healthcare challenges identified and discussed in Chapter 2; together with patient misidentification, patient flow, healthcare workforces, physician punctuality, and availability of medical equipment. All these challenges are reasons for a healthcare provider to establish the need for change.

Saudi Arabia has started acting on its collective need for change, both established and addressed by its Vision 2030 and the National Transformation Program (NTP) in 2016. As previously discussed, the NTP outlined 18 initiatives, specifically for the improvement of the Ministry of Health by the end of 2020. These initiatives establish the need for change in the following areas: - localisation of the pharmaceutical industry; - ambulatory service speed of response to 911 calls; - reduction of obesity, smoking, and of traffic accidents, through intervention by the National Centre for Disease Control and Prevention and Public Health; - development of emergency room and intensive care unit for provision of services with required speed and quality; - organisational transformation for primary healthcare facilities; - improvement of training and number of health practitioners; - and proliferation of essential safety standards across all medical facilities, - and several more (NTP, 2016).

It is generally apparent when change is needed in an organisation: hospital products and medical assets are wasted, healthcare personnel are underutilised, and operational procedures become overly bureaucratic (Hall et al., 2016). Emphasis on healthcare has shown clear lessons concerning the places in which improvement is not only possible, but also necessary. In New Zealand, it was identified that the health system needed reform. Specifically, the system lacked clear goals and strategies, proper consultation with stakeholders, and the utilisation of leaders. Some policies were also never given enough time for thorough evaluation, resulting in uncertain changes in the future (Jolley et al., 2008; Keene et al., 2016). The development of technologies has progressed faster than organisations have been able to understand how to best use them. Payne (2013) looked at how advancements in Information Technology have contributed to the nursing profession and healthcare in general. One of these changes is the transition from paper to electronic patient charts, which requires both structural and behavioural changes. Since this technology improved accuracy and access to patient information, the inevitable resistance to change by nursing staff had to be countered with convincing arguments on why they would benefit. Studies concur that this switch from paper to electronic charts reduces the time nurses spend each day on documentation, with the added benefit that writing is perfectly legible and easily in mutable languages (Sheikh et al., 2013). This gives nurses more time to focus on patient care. With proper care, change can be implemented for any individual or organisation (Moore et al., 2017).

As cost and patient numbers increase, healthcare stakeholders need to operate more efficiently, lower their unit costs, raise their quality levels, and identify ways to optimise the value of their limited resources (Morris, 2016). Also, the focus must now turn to a vehicle for managing this change.

4.4.4 Change Management

Change Management is a structured discipline that requires the evaluation, preparation and implementation of operating, tactics and strategies, followed by the analysis of its sustainability while in practice (Al-abri, 2009; Aljohani, 2016). Therefore, it covers all the lifecycle stages outlined by Cresswell et al. (2013), and it will be applied for the change approach here, through its preliminary steps of establishing the need for change and of building consensus.

Change Management requires a combination of technological and people-oriented solutions (Al-abri, 2009). Even with advanced investigations into the best practices for change-management, indices have shown that only one in three efforts at organisational change is successful from the perspective of the organisation's leaders (Aljohani, 2016). The literature acknowledges issues of resistance to change, but also that more research is needed. The organisational change can be divided into four elements: strategic, operational, cultural and political changes. Operational changes can include business operations and automation. Strategic changes can address business strategies, such as changing the benchmark from revenue-based to market share based. Cultural changes affect the organisation's method of conducting business, such as treating patients in healthcare (Aljohani, 2016). The combination of these factors means that no single approach can ever be applied universally, and that careful evaluation of each organisation, in its own social and time-based context, is crucial to improve the transition by successful Change Management. This section will provide a discussion of Change Management, and will demonstrate its usefulness in establishing the need for change.

4.4.4.1 Change Management in Healthcare

The complexity of healthcare is exacerbated by the competing interests of its practitioners and administrators (Clarke et al., 2017). Although, it is obvious that management of hospitals and other healthcare providers must be performed with physicians and nursing staff in mind, in practice, change is not always considered with the improvement of healthcare at the forefront of decision making. Antwi and Kale (2014) state that *'managing organisational culture is increasingly viewed as an essential part of health system reform.'* The management of these continuous and ongoing changes is the subject of change-management, which encompasses the handling of the complexities associated with the evolving processes within an organisation (Al-abri, 2009). Due to the increasing significance of more data-driven and people-centred opportunities, change-management is a critical topic for discussion when considering improvements in healthcare. The lack of relevant literature has constrained change-management being put into practice in healthcare. Case studies take the broadest and most in-depth look at how change-management is currently performed, or at how it could be improved (Antwi & Kale, 2014). The complexity of each healthcare institution makes for more factors demanding consideration, with resistance to change being more significant than in other organisations (Aljohani, 2016). After surveying healthcare practitioners in South Australia, Jolley et al. (2008) produced several factors they believe should be recognised universally when planning for healthcare reform:

- *Clear goals and vision that are accepted and understood by key players*
- *Opportunities for local communities to have input on how services are organised and run*
- *Accountability mechanisms that report to all stakeholders (including local communities)*
- *Strong leadership, and policies that are informed by evidence*
- *Minimising the influence of power brokers and political ideologies.*
- *Available resources to enable monitoring and evaluation of system structure and governance*

These factors address the challenges discussed in the next section, specifically challenges of planning, consensus, communication and resistance, as identified by Aljohani (2016). Jolley et al. (2008) focus on the relationship and knowledge sharing among all members of the organisation, no matter what place they hold in the hierarchy of power, while the last point in the list emphasises the process of planning, evaluating and sustaining the change. Even with these key factors having been identified, there are countless ways to approach them for best results.

4.4.4.2 Change Management Challenges

Most problems facing managers in charge of organisational change relate to the increased complexity and speed of change currently required. Understanding the behaviour and culture of an organisation's employees is one of the most common difficulties, one that is especially important in change-management. Resistance to change, often an expected obstacle, requires knowledge of the people's working procedures and habits, in order to teach them how to improve with the change (Aljohani, 2016).

Strategic change provided by the framework is expected to be regular and planned, usually through a top-down approach. Strategic change makes it clear how the organisation is compatible with the intended vision. Aljohani (2016) asserts that '*the most common mistake made is using past knowledge of change-management and applying it to a current problem*.' This statement is representative of how each organisation, in its own time and culture of people, requires individual attention. The uniqueness of every occurrence in which change-management is utilised, results in a set of challenges. One of the most important challenges to overcome for the purpose of successful change-management is planning, which allows for a better understanding of how the change will affect the organisation. This planning step is also the place for consensus to be built within the organisation, as this can decide the success of even small changes. Consensus can involve the speed at which changes are applied, how many people are in agreement on the proposed changes, or steps to change, and awareness on how all members of the organisation are involved in the change (Abri, 2007; Aljohani, 2016; Jolley et al., 2008). Change-management should assign to people roles for facilitating the change, and should plan for a particular timeline, with priorities and deadlines to ensure steps are completed when expected (Aljohani, 2016). Similarly, communication regarding changes is a difficult obstacle, especially in an organisation such as a hospital, in which nurses or physicians may be a close-knit group and speculate about changes in the workplace (Aljohani, 2016). Communication about realistic expectations and proper training on new procedures (i.e., by IT on new technologies) are some of the most effective solutions in overcoming this major challenge (Aljohani, 2016; Jolley et al., 2008).

4.4.5 Considering Saudi Healthcare Options with the CoP

Following the establishment of the need for change and the consensus of the organisation's members, various options must be considered with sufficient time and resources dedicated to such a search (Cresswell et al., 2013). As a new information technology system may be in place for the long term, it is important to consider all of the organisation's providers and suppliers. Cresswell et al. (2013) suggest visiting other healthcare providers when they have adopted similar technology. Solutions can include the construction of a customised system for local needs, customisation of the current system, or using a new and standardised solution. The greatest enemy of customisation is usually financial cost, but the organisation's budget should be established before this step (Cresswell et al., 2013; Sheikh et al., 2011). CoPs are best utilised during this stage, so that the organisation can become aware of all available options for the implementation of a RFID/ZigBee integrated system. These options involve manufacturers, suppliers, engineers, construction companies, system providers, external, internal experts, and more. This stage includes the composition and analysis of business cases, which is especially important for a technology such as RFID associated with costs.

4.4.6 Select an Appropriate System with the CoP

Once the need for change has been established, consensus among the members of the organisation has been built, and the CoP has provided all the options in the context of the user requirements and costs and benefits of the systems under analysis, the chosen system is nearly ready for implementation. Selecting the most appropriate system requires use of the holistic framework presented in this chapter. A factor-by-factor analysis is provided, alongside the refinement by the CoP, as shown in Figure 4.12. The analysis of these costs and benefits requires devoted time and resources, or the process may make inaccurate assumptions or ignore important statistical figures or staff input.

4.4.7 Plan with the CoP

Of the many models in existence on change-management, Lewin's 3-step model provides a generalised sequence of change, involving unfreezing, moving, and refreezing. This can be effective for healthcare organisations in particular, because of its adaptive nature and its plan to meet constantly ongoing demands (Antwi & Kale, 2014; Payne et al., 2013). Of these three steps, refreezing is the focus of this section, as it provides emphasis on training staff, as shown in Figure 4.10.

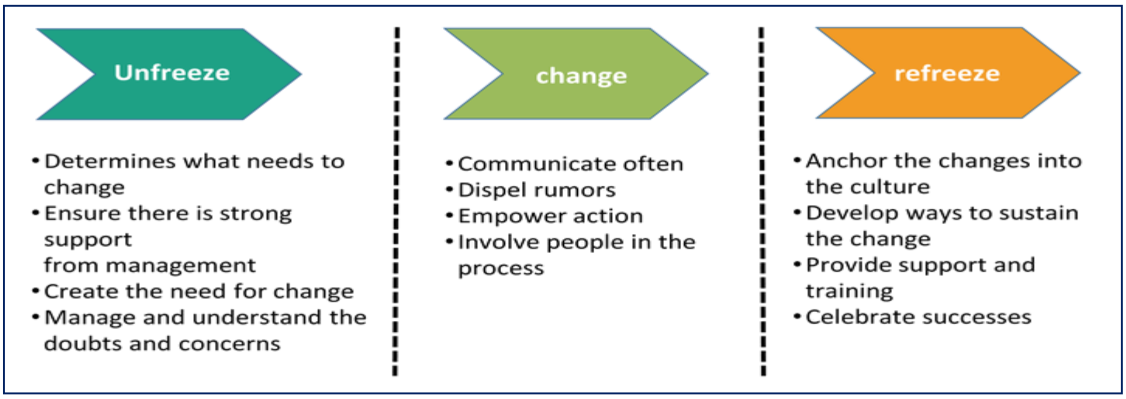


Figure 4.10 Lewin's 3-step model

Payne et al. (2013) provide an example of the application of Lewin's 3-step model with regard to nursing staff, a vital component of every healthcare facility. The three steps will be followed here so that the third step, specifically centred on human aspects such as training, can be best understood. The first step in their procedure requires the identification and prioritisation of the driving and restraining forces in the workplace of the nursing staff. Information and input would be gathered from other healthcare professionals as well. Driving forces include the desire to improve documentation methods, the belief of newly generated accuracy and comprehensiveness, and positive attitudes towards computerising records. Restraining forces include inadequate training, unsupportive management, reluctance to learn, insufficient finances, and pessimistic workplace culture. The step following the identification of these forces is to plan how to strengthen the driving forces and weaken or eliminate the restraining forces. Once the plan is analysed, it would be implemented while the changes are closely monitored, so ensuring that nursing staff's attitudes are positive towards accepting the changes and helping to adjust their behaviour accordingly. By this point, the principles of change-management would ensure that the nursing staff's input is being heard and utilised, and the CoPs would promote the nursing staff's continuous involvement in the selection of a new system, whenever their input is relevant. The last step for this model is that a specific case study involves stabilising and re-evaluating the change to electronic documentation, which requires the provision of ongoing support and education of the processes and technological systems. This training, although conducted prior to or concurrently with system implementation, demands close monitoring by management and continuous care, as the system is bound to fail without supervision and analysis (Schoenwald et al., 2013). Only the first of these three steps is utilised for the approach outlined in this chapter, which is that after the plan is formed and analysed, we consider the options available through the vehicle described in the previous Section 4.4.5. This final step, however, continues alongside the constant evaluation and maintenance of the system, as discussed later, and all aspects of this final step (training, evaluation and maintenance) support each other and depend on one another for ensuring the success of the system.

It is therefore critical that implementation strategies for new technology systems in healthcare tailored to the organisation's circumstances, infrastructure and people. The circumstances will have been heavily considered while evaluating the various choices available to the organisation, keeping in mind the many criteria discussed above. The organisation's infrastructure is also an essential aspect of the planning step, but this again should be addressed while considering the options. The improper or inadequate training of staff is a failure identified in the change-management literature (Aljohani, 2016; Jolley et al., 2008). Improved training also corresponds with better satisfaction with the new technologies in use. Inadequate training is often linked with frustration or complete avoidance of the system (Byrne et al., 2016).

Best practices in training staff centre on tailoring the training to each staff role, such as for a nurse or physician, including practice with the new system. Ideally, practice includes, when possible, a simulated environment reflecting actual conditions. Additionally, training has the best results when done shortly before the system's implementation, as highly technical lessons are easily forgotten without practice over time. Tailoring training to individual staff also means understanding the persons' current level of technological competency, and the level at which it must be maintained in order for the adaptation to the new system to be smooth. This is an advantage of utilising the CoP, which will provide insight on the best training strategies, based on the current level of technological competence of staff within the organisation. Mao (2016) acknowledge that continuous training is sometimes necessary when systems are subject to consistent upgrades (Mao, 2016). Studies of successful implementations have shown that training requires roughly 40% of the implementation budget, and that this is often an area left underfunded (Sponem & Lambert, 2016).

4.4.8 Continuously Evaluate Progress and Maintain the System

The importance and consistency of evaluation is widely understated and undervalued, as it is often simply an afterthought to implementation. Although in this chapter the focus has been concentrated on the planning and strategizing steps, time and effort must also be devoted to continuous evaluation as well (Poza-Lujan et al., 2016). The information technology system for which this study is relevant is specifically for real-time data, and the benefit of this type of system is that is can be continuously adaptive in its software, while the hardware and other underlying infrastructure remain constant. Once an RTLS is implemented in a healthcare organisation, evaluation becomes much less costly than for any traditional system, and the CoP established for the implementation of this system should be utilised for adhering to consistent evaluation metrics, and assuring that the technology is adapting to new obstacles. The information is designed so as to be automatically stored and analysed, as will be elucidated in later chapters. Similarly, the information is designed to be useful to CoPs for better analysis and future implementation. The selection process will generally adhere to the steps outlined in this chapter, but the purpose of the evaluation step is to determine whether improvements can be integrated, or processes further enhanced. Timely user feedback allows for problems to be identified early in the implementation phase, as there have been instances in which staff were not given the opportunity to do so and subsequently threw a computer monitor from a hospital window out of frustration (Reilly et al., 2013).

Evaluation should begin with activities that assess existing and anticipated workflows, monitor positive and negative consequences, and track new methods developed after implementation (Murray et al., 2016). Just as performance metrics were utilised in the selection step, evaluation metrics can greatly increase consistency across the organisation and over time. These metrics can include clinical outcomes and processes, provider adoption and attitudes, patient knowledge and attitudes, workflow impact and financial impact (Cusack & Poon, 2007). Cusack and Poon (2007) provide an evaluation plan that separates metrics by quantitative and qualitative measures, and advocate for metrics to be sought out that relate to the specific organisation. Evaluation may continue for years after implementation, as outcomes may not be apparent immediately. This step may ultimately lead to the establishment of the need for change once again, either when the system becomes obsolete, or if a new solution has become available within the organisation's budget (Sheikh et al., 2011).

Like system evaluation, system maintenance is often overlooked or underappreciated. System maintenance costs relate to support, infrastructure and upgrades, as well as costs derived from potential system changes as the organisation changes over time. These costs are usually underestimated, as they may have not been considered in the selection process, and since they cannot be predicted with much accuracy, due to the unknown long-term effects that the system itself will have on the organisation (Connon et al., 2012). Stunted or lacklustre progress can be a deterrent to maintain the system, but the timeline and its deviation from expectations must be appreciated, so that the technologies can have enough time for their embedding to take place within individuals' processes and data can be analysed and used for successful change. Research by Cresswell et al. (2013) indicates that an organisation's expectations often far exceed reality in the short term, and this can easily result in negative attitudes emerging, or abandonment of the initiatives. The practice to avoid this outcome is therefore to enact proper management of expectations for individuals within the organisation, laying them out clearly in the training stage.

4.5. Holistic Framework Refinement with CoPs (2nd Version)

As opposed to a systematic literature review, this research utilises CoPs in order to determine the most relevant factors among the many listed in the sections above. It was acknowledged previously that the CoP for this study provided a model for choosing the appropriate technologies that meet the hospital's needs, standards and expectations in achieving the goals set. The researcher provided the CoP with the initial set of factors with classifications by the four chosen contexts to establish a foundation on which the CoP could evaluate the set and develop it further through combined knowledge and information transfer as defined in the role of CoPs. The list, as depicted by Figure 4.4, was used for discussions among the CoP, with the researcher acting as a member, such that it could be determined if there remained any overlap between factors and if any aspects of framework adoption were still missing. These discussions resulted in the additional of several factors and the combination of some into broader concepts. The CoP now sets out these factors as a refined holistic framework for the consideration of a health information technology system, evaluated for the side-by-side comparison of various technologies when selecting an appropriate system. Any integration of a new technology system requires advanced analysis of its benefits, weighed against its costs.

Within the technology context, CoPs reviewed and emphasised the factors that were previously developed by the author, based on the literature. These factors are design, reliability, accuracy, energy consumption, integration, maintenance and robustness. A system's reliability is determined by several previously separated factors, including: - *accuracy*, measured in square units, and which determines the difference between estimated and actual location of the devices; - *update rate*, which relates to using effectively real-time tracking; -*system integrity*, which relates to its reliability in accordance with technical specifications such as notifying the user in case of malfunction; - *robustness*, which is the system's resistance against physical damage, theft, jamming, or unauthorised access.

RFID can be considered scalable due to its easy installation of extra infrastructure, and ZigBee can expand its coverage through added networks (Alliance, 2008; Yazici, 2014; Farid et al., 2013). Another interactive criterion is the *design of the system and devices*, which is ideally operable by individuals with any technical background. A good design is user-friendly and acceptable within a hospital environment. Within the technology context, CoP refinement resulted in the factors of coverage, the update rate and frequency interference added to the list, as seen in Figure 4.11. Trouble can arise from a system's *frequency*, or the wavelength of the carrier. The system must not disturb other medical devices, or the consequences can be severe. This is a place where RFID is at a relative advantage (Liu & Sahandi, 2009b). Next is the area of *coverage* of a technology. Ideally, a technology can cover the entire hospital, thus giving access to its information from anywhere. Both RFID and ZigBee systems have satisfactory indoor ranges (Farid et al., 2013).

Within the organisational context, CoP refinement added the factor of attitude to the change. Resistance to change, often an expected obstacle, requires knowledge of the people's working procedures and habits, in order to teach them how to improve with the change (Aljohani, 2016)

Within the human context, CoP refinement added the factors of infection control and privacy. This is the ability of a technology to *control infection* via compliance with the hospital's hygiene policy. A user requirement is for devices attached to patients to be disposable, or else coated by a protective material. A good technology reduces frequency of infection. On the patient end, *privacy* is important because medical records are confidential, and technology always risks privacy breaches.

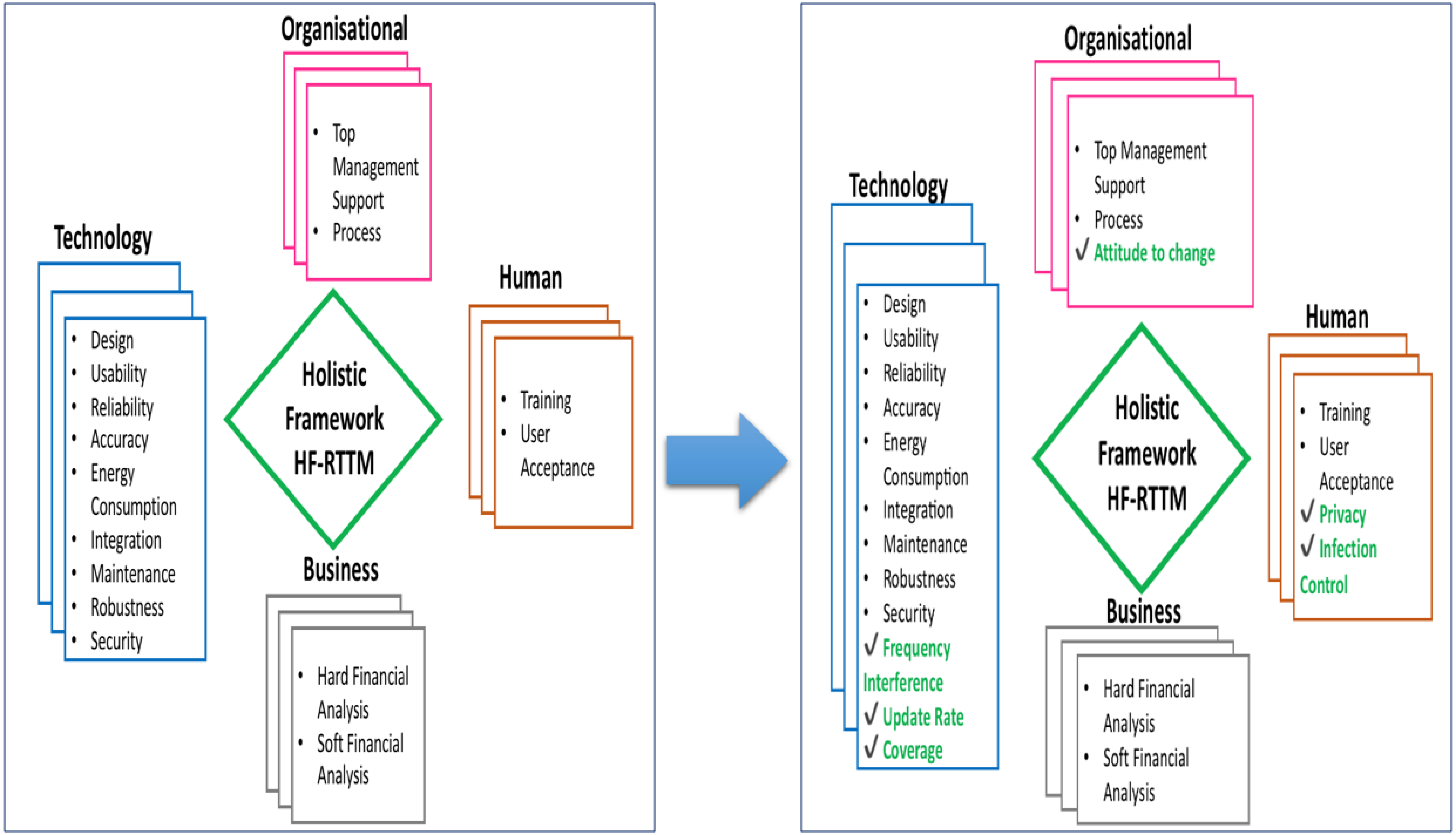


Figure 4.11 The Initial version and the Second Version of the Framework after Refining by CoP

4.6. Conclusion

This chapter has developed a holistic framework for real-time tracking and monitoring in Saudi healthcare. This framework was developed and implemented with a Health Information Technology Lifecycle Approach that modified the four-stage lifecycle of Creswell et al. (2013) and adopted a five-stage lifecycle designed specifically by the author.

From the consideration of the multiplicity and complexity of the factors involved, the author concluded that a Community of Practice, CoP, would be essential as a guiding element for the purpose of considering all available options for adopting a new system, and for selecting an appropriate one, in consideration of the various user requirements and of the costs and benefits of each alternative. Therefore, the author formed a CoP, which has been involved in all aspects of the development of the framework.

Change Management was considered in the context of applying its principles to establish the need for change and for building consensus among the members of an organisation. It became increasingly clear how fundamental was the importance of training healthcare personnel, and of continuously evaluating progress and maintaining the system. The CoP emphasised the dangers of failure due to lack of financial planning or to unachievable expectations. This approach, therefore, applies aspects of CoPs and change-management for ensuring that a tracking and monitoring system is analysed adaptively in the context of the healthcare organisation's circumstances, needs and constraints, so that planning and well-established strategies are spread throughout the organisation.

The following chapter employs the use of the questionnaire developed for this research and uses the questionnaire results to further refine this holistic framework.

Chapter 5 Current Saudi Healthcare System Challenges, and Necessity of a Tracking and Monitoring System in Saudi Hospitals

5.1 Introduction

This chapter presents an investigation to examine current challenges in the Saudi healthcare system, and the necessity for a real-time tracking and monitoring system for patients, staff and medical assets in Saudi Hospitals. The study utilised responses from various members of the population of Saudi Arabia, to be relevant and informative for future managerial decision support in Saudi Arabia in implementing an information system to track and monitor in real time patients, medical staff and medical equipment locations and status. This survey is a vital tool in meeting the need for change, as established in Saudi Arabia's Vision 2030 (NTP, 2016). This study also seeks to provide a holistic view, by allowing multiple stakeholders to participate in the survey. This is achieved by using a survey method to examine the challenges identified previously from the literature review.

This chapter is organised as follows. It begins with a description of the questionnaire, to overview its structure. Next is the design of the questionnaire, which discusses its development, its contents, its pilot version, its administration and distribution, and its reliability. This is followed by a description of the method by which the data was collected, the analysis of the data, and a discussion of the overall findings.

5.2 Description of the Questionnaire

The researcher used a survey technique to accomplish the research objectives, and to examine the existing challenges affecting the Saudi Arabian healthcare system. According to Saunders et al. (2009), surveys are the best strategy when using questionnaires for extensive research. In general, a questionnaire includes all techniques for data collection, with each respondent asked to answer the same set of questions in the same, predetermined order (De Vaus, 2002; Saunders et al., 2009). A questionnaire is used in this research to obtain a cross-sectional view of the generalised population of Saudi Arabia, so as to support an appropriate framework for this research. This choice of research method was also used because the availability of contemporary data on these questions was not available. A questionnaire was designed with 23 questions, which were structured as follows (please see Appendix A5 for the full questionnaire). Additionally, details on the questionnaire's development are described in Section 4.3, as also the attainment of reliability and consistency, which is of particular importance for any research (De Vaus, 2002).

The survey was divided into four parts. The First part acts as the cover letter and consent form for the questionnaire. It also provides information about the study and the researcher, to allow the participants to raise any concern about the questionnaire. This section also indicates that Staffordshire University's code of ethics that was followed during all the phases of this research – see Figure 5.1.

Tracking and Monitoring Patients, Staff and Assets

STAFFORDSHIRE UNIVERSITY

Research Title
Smart e-Health Framework for Tracking and Monitoring Patients, Staff and Assets to Support Decision Makers in Saudi Arabia Healthcare

Researcher Contact Information	
Name	Awad Ali AlYami
Phone	00966 544150111- 0044 7762585405
E-mail	A033791C@student.staffs.ac.uk

Description

This study is being undertaken as part of the PhD research study for Awad Ali AlYami. The Ministry of Higher Education in Saudi Arabia sponsors this research. The sponsor of this research will not have access to the obtained data.

The purpose of this research is to develop a smart e-health framework for tracking and monitoring patients and assets to support decision makers in Saudi Arabia healthcare. As a researcher, I request your help by participating to the questionnaire of this study. This study will benefit the healthcare sector in Saudi Arabia, as it will provide required support to the decision makers in Saudi Arabia healthcare.

Please note that:

- DO NOT participate in this questionnaire if you are vulnerable to coercion or undue influence (e.g., unable to consent, less than 18 years, prisoner, etc.).
- All answers will be treated in confidence and names of participants are not required.
- You can stop at any time during the questionnaire.
- While your cooperation in answering every question will help us understand important questions with regards to telemedicine acceptance, you are not obligated to answer every question.
- Your participation in this project is voluntary.
- If you agree to participate, you can withdraw from participation at any time without any consequences (incomplete and dropped questionnaires will be counts).
- There are no direct benefits to you for participating in this research.
- There are no risks associated with participation.
- By your return of the completed questionnaire, you consent to participate in this study.
- This questionnaire is available in two languages (Arabic and English).

Figure 5.1 A Screenshot of The First part of the Survey

The second part included questions related to demographic information; including gender, age, computer skills, educational level and role in the healthcare sector. The purpose of these questions is to assess the general background of the respondents, and possibly to generate deeper analysis. The third and fourth parts involved the main questions on the needs of real-time tracking and monitoring people, staff and medical assets in Saudi Arabia. The third part required a yes or no response and the forth part asked for either a single-answer to multiple choices, or for the level of agreement based on a single 5-point Likert scale (Likert, R. 1932); as it is recommended when implementing self-administered surveys (Hair et al., 2006) and as it has been used widely in the healthcare context (van Dyk, 2014). The Likert scale is an interval scale that is used to capture the respondents' opinions regarding a given subject or topic (Boone & Boone, 2012). The total number of questions was designed so that the total time to complete the questionnaire was expected to be under 20 minutes, in order to get favourable responses.

5.3 Questionnaire Design

The questionnaire was designed specifically for this research, based on the reviewed literature, to obtain the necessary data. The questions were formed and analysed for their wording, bias, ambiguity, whether they were leading, and other factors. This section outlines this process and the ultimate reliability for analysis., having followed the guidelines under which a questionnaire should be designed (Fellegi, 2010). These are as follows:

- Gather data efficiently with minimal errors,
- Be respondent-friendly,
- Lead to cost and time reduction in data collection.
- Comply with ethical standards.

These principles and the University principles were followed and strictly adhered to during the design and administration process, as detailed in following sections.

5.3.1 Development of the Questionnaire

The need to understand the problems of the general population of Saudi Arabia has grown with the country's healthcare challenges and with the slow pace in adopting e-Health solutions.

Once a clear need was established (Healy, 2008), a suitable approach and methodology for information systems implementation in Saudi Arabia was developed.

This research began before the publication of Saudi Arabia Vision 2030, as the problems were already visible, and the existing literature prior to 2015 identified the various deficiencies. Among these were patient misidentification events, which can be fatal, and many of which have the potential to cause harm (ECRI Institute Patient Safety Organization, 2016) The National Patient Safety Agency (NPSA) reported that more than 42% of total incidents were due to patient identification errors, and indicated that, on a monthly basis, more than 500 patients admitted through A&E resulted in misidentification that led to incorrect medications, GP details, and medical records/notes (Ponemon Institute, 2016). There was a consequent longer patient waiting time to be seen, which is 24 minutes in the UK and USA, while it is 161 minutes in the Middle East. The poor patient flow leads to higher healthcare costs and greater chance of harm to patients (De Silva, 2013). Other costly problems were: physicians' tardiness, with more than 20% of physicians in one Saudi tertiary care hospital arriving more than 60 minutes late (Clinic Management Department, 2014); and misplaced and lost medical assets, which wastes up to 60 minutes of search time per shift for up to 85% of healthcare practitioners (Dare, 2009).

These areas of deficiency were selected to create questions that would provide more nationally generalised results, to identify the significance of each deficiency.

The respondent's demographics questions were standard, but included also the level of computer skills and the role in the healthcare sector. As the questionnaire inherently deals with information systems, familiarity with technology is relevant. The question on healthcare roles ensured representation of various healthcare professionals. The six yes/no questions were all aimed at understanding current opinions on healthcare practices in Saudi Arabia, as were the first two multiple choice questions. The last nine questions asked for the respondents' opinions or agreement with various aspects (i.e., productivity, accuracy, efficiency), regarding the implementation of a new real-time tracking and monitoring system. These questions were developed to address collectively and directly deficiencies such as waiting time, asset misplacement, and patient protection, as outlined above, for the determination of the factors that a new system must make its priorities and to confirm the needs of the healthcare sector.

5.3.2 Content of the Questionnaire

All questions in the survey are categorised as closed questions, which are those where response categories are listed with the question (Fellegi, 2010). Additionally, the instructions requested the respondent to only provide a single answer among the categories listed. The questionnaire was divided into three parts: demographics, yes/no questions, and multiple-choice questions. The demographics questions, as indicated above, asked for the respondent gender, age, computer skills, educational level and role in the healthcare sector. All the yes/no questions addressed current circumstances; the first three asked for the respondent's hospital's ability to perform various tracking, measuring, and verification activities; the next three concerned the respondent's level of satisfaction and need for a tracking and locating system. In the fourth part, the first two questions continued to address the current situation, including:

1. Patient waiting time
2. Shortage of medical equipment.

The final nine questions, all of which used a 5-point Likert scale (ranging from 'Strongly agree' (5) to 'Strongly disagree' (1)), asked respondents to express their beliefs and opinions on the ability of tracking and monitoring systems to improve various aspects of their hospital. These included:

- Efficient locating procedures.
- Patients' safety.
- Tracking controlled areas.
- Improving patient care
- Improving staff productivity.
- Improved patient/room turnover and hospital utilisation.
- Tighter asset control and lower replacement costs.
- Preventing and eliminating human and medical error.
- Increasing accuracy of location access.
- Helping in performance and efficiency, specifically in Saudi Arabia.

These questions were deemed the clearest and the most thorough for understanding the respondents' current situation and their feelings on implementing tracking and monitoring technology in real time, to resolve some of the deficiencies identified in the literature.

5.3.3. Pilot Testing the Questionnaire

The next stage is the reviewing process, which ensures the content validity of the questionnaire. Content validity is the process of ensuring that the items in the questionnaire represent their constructors (Saunders et al., 2009). This can be achieved by identifying the items carefully from the reviewed literature and experts' judgement (Saunders et al., 2009; Moore & Benbasat, 1991). Furthermore, research requires the rigorous evaluation of each question in a survey, and of the questionnaire as a whole, which is called '*pilot testing*' This process is performed to establish question phrasing, question meaning for each respondent, and to determine that a sufficient range of questions has been developed. Other purposes can include language errors, and the time required to take the questionnaire, which for this questionnaire was not a significant issue (De Vaus, 2002).

A pilot survey was sent to 10 specialised individuals in the KSA who have experience in both healthcare and Information Technology, to review the preliminary questionnaire. Based on the feedback from the pilot survey responses, amendments to some questions were made for phrasing and interpretative meaning, but the number of questions was perceived appropriate and no significant changes were required. To ensure consistency and accuracy of meaning, all items were prepared in English and then translated into Arabic, and back-translated into English by a trilingual translator. The final version of the questionnaire was stored online on a Google document application in both English and Arabic. An online questionnaire was chosen for this research since it provides advantages for the researcher and for the participants. For the participants, an online questionnaire can protect their privacy and give them the opportunity to participate in the questionnaire at a convenient time for them, with enough time to understand the questions (Singleton, 2009). For the researcher, the advantages of using an online survey include saving time by easing data-processing activities and eliminating the interviewer bias (Selm & Jankowski, 2006).

5.3.4. Administration of the Questionnaire

The research population is a well-defined collection of people or objects that is studied by the researcher (Saunders et al., 2009). However, for some types of research, it is not practicable to collect data about the whole population of the study, due to its large size. Thus, sample size is an alternative way of collecting data that represent the population of the study (Saunders et al., 2009). The population of this study comprises individuals who regularly work in hospitals, as this is the group of people most affected by the subjects of the questions. The data for this research were obtained from a sample of the population of Saudi Arabia. Respondents were found using a technique called the '*snowball'* method, which takes an initial group of respondents and requests them to recommend further suitable persons to complete the same survey (Voicu & Babonea, 2007). The snowball technique was implemented in this study as it has been applied in the Saudi healthcare context in other studies (Alkraiji et al., 2013; Aldraehim & Edwards, 2013). With this method, respondents were invited, via multiple appropriate channels in social networks, (including but not limited to Twitter, email and LinkedIn) with the invitees only allowed to participate if they held a role within the healthcare sector. The respondents completed the self-administered questionnaire (for which both English and Arabic versions were provided) and the data was gathered online.

5.3.5. Data Collection

The definition of data collection is '*the process of gathering the required information for each selected unit in the survey*.' The specific type of data collection method was self-enumeration, which requires no assistance from an interviewer and is facilitated for this research through the Internet. As this is a computer-based method, is it termed Computer-Assisted Self Interviewing (Fellegi, 2010).

Invitations were sent out to an initial set of respondents believed suitable for the survey, and through the Snowball method, more respondents were obtained. Data was collected over two months (July & August 2015), until a reasonable number of response were obtained. The online survey produced 360 responses. However, only 220 responses were used, since some of the questionnaires were not fully completed. A sample size above 100 is sufficient to perform many statistical tests such as factor analysis, as suggested by statisticians (Williams et al., 2012). Additionally, this was considered acceptable, as it doubled the recommended number of 100 responses believed necessary by Gorsuch (1983) and Kline (1979), and surpassed Guilford's (1954) recommendation for 200 responses (MacCallum et al., 1999). All the online collected data was converted to Statistical Package for the Social Sciences (SPSS) format for analysis. The questionnaire was coded within SPSS version 22. In SPSS, each question in the questionnaire was typed as a variable, with coding options where applicable. The further reliability of the questionnaire is examined below.

5.3.6. Reliability of the Questionnaire

Statistical reliability measures include the Pearson Correlation Coefficient and Cronbach's alpha. Both are used as measures of internal consistency, and are one of the main tests of reliability (O'Brien et al., 2008; Saunders et al., 2009). The Pearson Correlation Coefficient is a measure of correlation, which range from -1 to 1 (Eisinga et al., 2013). The statistic represents how closely two variables co-vary; it can vary from −1 (perfect negative correlation) through 0 (no correlation) to +1 (perfect positive correlation) and if the coefficient is a positive number, the variables are directly related and indicate a strong correlation (Eisinga et al., 2013). The Pearson Correlation Coefficient values as shown in Table 5.1 and range between (0.546) and (0.731), which is a strong correlation; therefore, the questions have a perfect positive linear relationship, which confirms the correlation of the survey.

Table 5.1 Pearson Correlation Coefficients

Part Number	Pearson Correlation Coefficients
Questions in Part 3	0.546
Questions in Part 4	0.731

Cronbach's alpha was developed to measure internal consistency of a test or scale and produces a value between 0 (unreliable) and 1 (perfect reliable); values greater than 0.5 are considered to be reliable and acceptable (Tavakol & Dennick, 2011). The questions in part three of the questionnaire produced a value of 0.572 for Cronbach's alpha, and the questions in part four produced a value of 0.816 as shown in Table 5.2; both values were found to be reliable and acceptable (Patten, 2011). These results confirm the internal consistency of the questionnaire: it can therefore be called reliable, as it passed both of these widely accepted statistical tests.

Table 5.2 Alpha Cronbach

Part Number	Alpha Cronbach
Questions in Part 3	0.572
Questions in Part 4	0.816

5.4 Data Analysis

In this section, the data will be summarised and their meaning interpreted, in order to provide clear answers to the research questions that instigated the survey, and following the definition of data analysis (Fellegi, 2010). Various means and distributions will be presented through numerical output (repetitions, percentages and average), diagrams and charts. The descriptive statistics given here are for deeper analysis in the following section. These sections structure the analysis into three sections: the demographics or profile of the respondents, the current challenges in Saudi Arabian healthcare system, and the need for a tracking and monitoring system for patients, staff and medical assets.

5.4.1 Profile of the Respondents

In terms of gender, the majority were male (84%) and the minority were female (16%) as shown in Figure 5.2. This statistic does not represent a gender bias within the survey, but rather the representation of gender within the current Saudi workforce. The World Economic Forum's annual Global Gender Gap Report (2016) revealed that Saudi women constitute only 13% of the native workforce (Baqi et al., 2017).

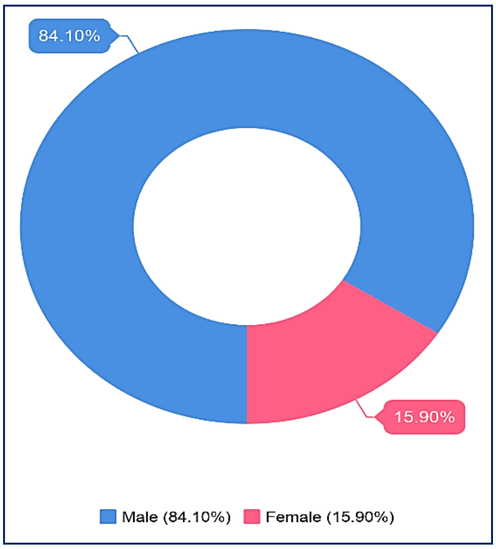


Figure 5.2 Respondents' Gender

The respondents' age groups are shown in the Figure 5.3. More than 80% of the total respondents were 40 or under, indicating a generally younger population that may have more familiarity with Information Technology, and therefore a tendency for better understanding and adaptability to new systems. The age demographics median is 30.5 which are consistent with Saudi Arabia's median age of 29.8 years (Haj-Kacem, 2015).

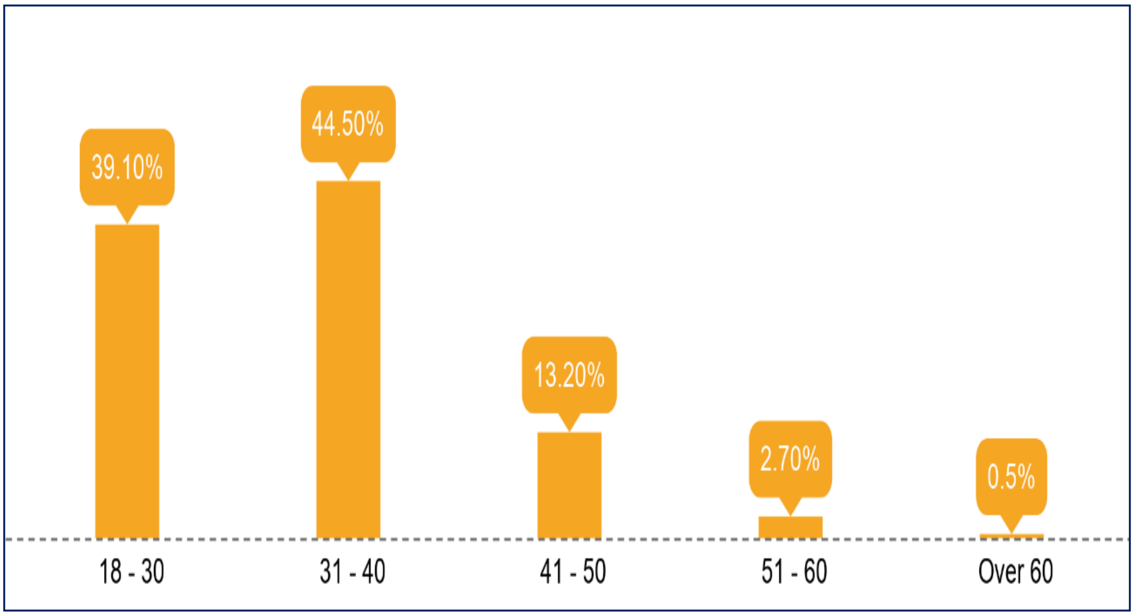


Figure 5.3 Respondents' Age Groups

As shown from the respondents' age demographics, computer skills are generally fair, with more than 65% of respondents claiming medium computer skills as shown in the Figure 5.4. Although, it is beneficial for this questionnaire that respondents represent all categories for this question, there is a possibility for variation in respondents' interpretation, regarding the meaning of 'medium' skills. Additionally, the level of computer skills need only be minimal for the completion of this kind of survey, which only demands following a link (to the survey) and selecting one of the options. The tendency is for healthcare practitioners to possess computer literacy to a level that allows for the completion of online forms or computer-based documentation, as proven in studies on shifts from paper-based to electronic medical records (NHS England, 2016; Stausberg et al., 2003).

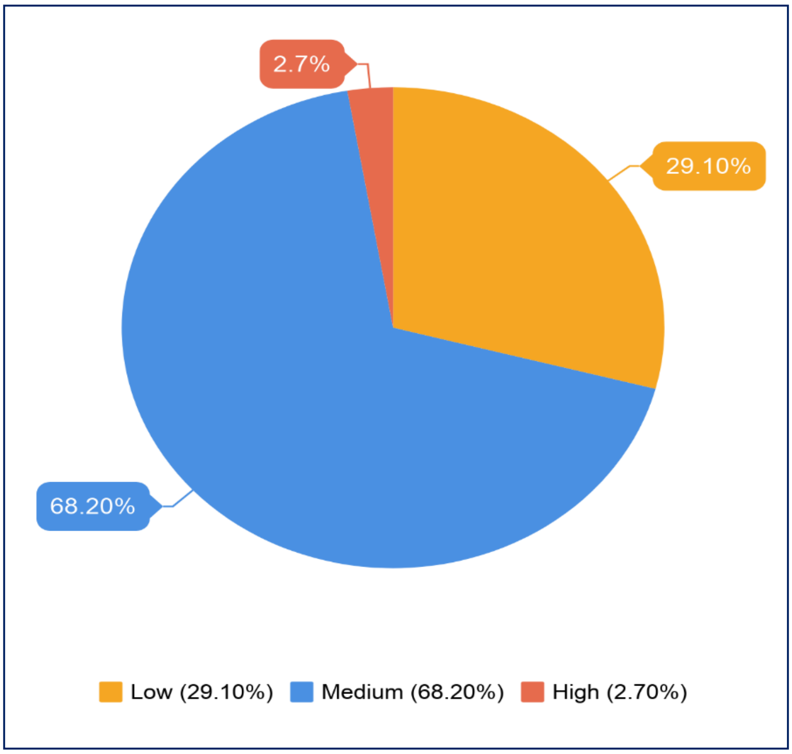


Figure 5.4 Respondents' Computer Skills

The distribution for the education level of respondents indicated that 49% have a bachelor's degree level, as shown in Figure 4.5. Additionally, 76% of respondents were graduates with a bachelor's degree or higher, which is an expected result in healthcare system in the KSA, when surveying people in a knowledge-intensive industry.

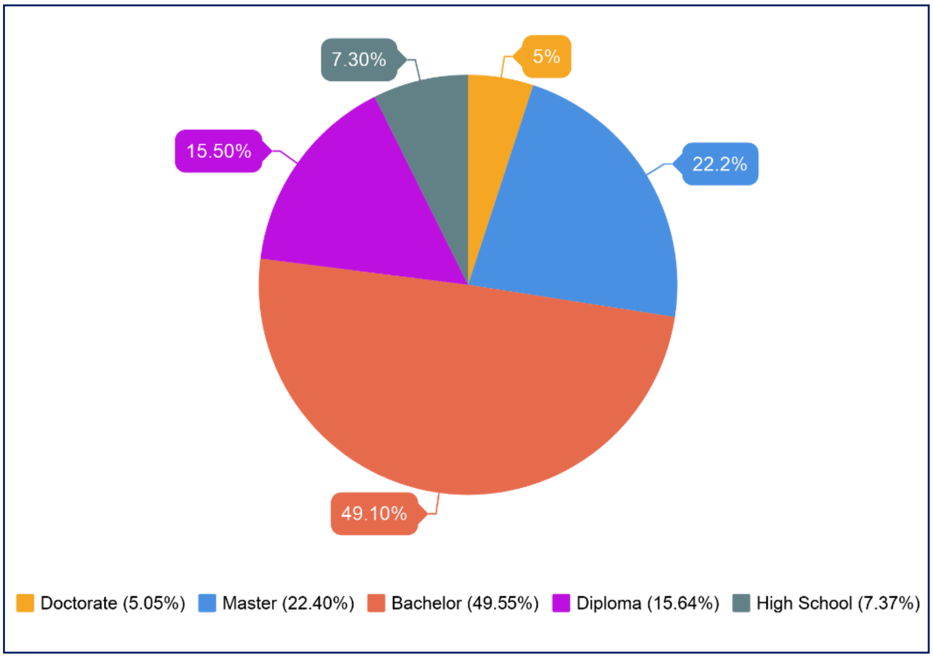


Figure 5.5 Respondents' Education Level

Lastly, this item represents the role of the respondents inside the healthcare organisations. The role of each respondent in the healthcare sector varied widely, with the most common being nurse (33%) and least common being administrative staff (10%). Each of the five identified roles (physician, nurses, ancillary staff, administrative staff and IT specialist) were therefore well represented by the questionnaire. This is similar to the actual distribution in Saudi healthcare organisations, where physicians and nurses make up the majority of the healthcare professionals (MoH, 2016). Figure 5.6 compares the questionnaire respondents based on their roles.

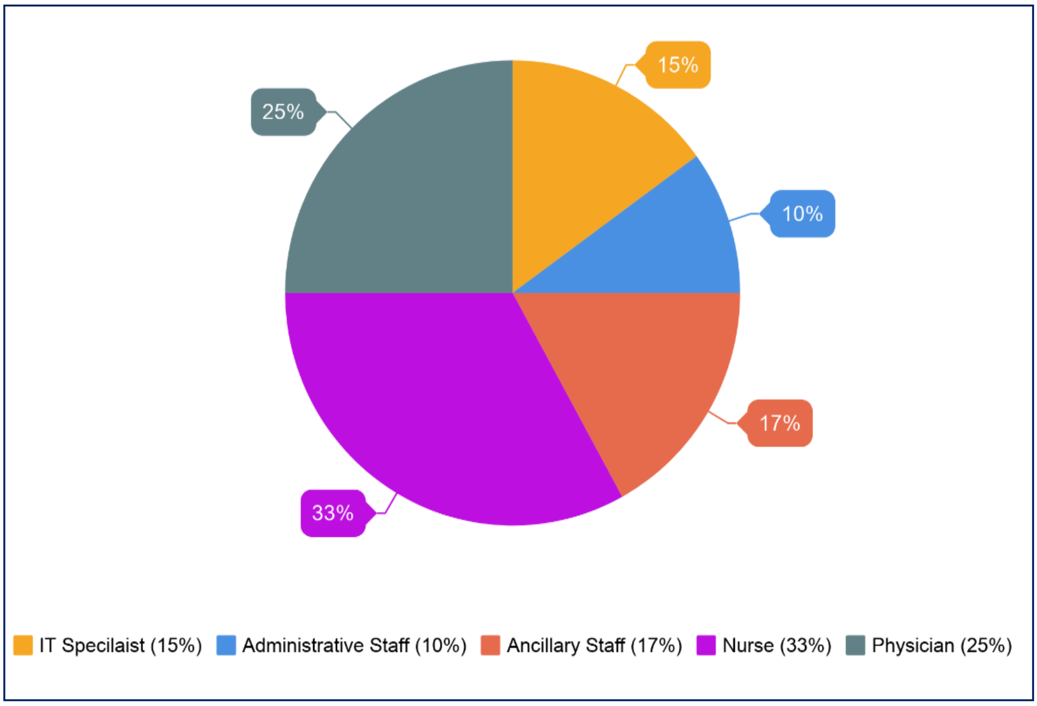


Figure 5.6 Respondents' Job

5.4.2 Responses on the existing challenges in Saudi Arabian healthcare system

To standardise the criteria for defining individuals' responses in the yes/no section, a value of 1 was assigned to 'Yes' and a 2 was assigned to 'No.' Therefore an average response from the sample less than or equal to 1.50 indicates a 'Yes' and an average response greater than or equal to 1.51 indicates a 'No.'

As shown in Table 5.3, the question, 'Do you feel there is a need for tracking and locating patients and assets in your hospital to assist and improving efficiency?' received the greatest consensus: 94% of respondents (an average of 1.06 on the yes/no scale) agreed that this was necessary. The remaining, yes or no questions, when averaged, result in more deficiencies being identified. The second strongest response came from the question asking, ‘Is there a system in place to measure staff productivity in your hospitals?’ for which 88% of respondents (an average of 1.88) responded ‘No.’ The third ranking goes to the question, ‘Can you track and locate patients and assets in your hospital?’ which received 79% response of ‘No’ (average of 1.79). Next strongest was the question, ‘Is your current system able to verify an individual’s status regarding access to areas like maternity, ICU and so on?’ which received 75% agreement in the negative (average of 1.75). The fifth ranking goes to the question, ‘Are you satisfied with the current practice of tracking assets at your hospital?’ which received a rate of 71% lack of satisfaction (average of 1.71). Least significant was the question, ‘Do you have frequent difficulty in misplaced or lost medical assets and mobile equipment in your hospital?’ which only received 51% confirmation (average of 1.49).

Table 5.3 Averages, Tendencies and Statements Ranking concerning the Current Practice Statements

Question	Yes (%)	No (%)	Average	Tendency	Ranking
Currently, can you track and locate patients and assets in your hospital?	20.90	79.10	1.79	No	**3**
Is there a system in place to measure staff productivity in your hospital?	12.30	87.70	1.88	No	**2**
Is your current system able to verify an individual’s status regarding access to areas like maternity, ICU and so on?	25.00	75.00	1.75	No	**4**
Do you have frequent difficulty in misplaced or lost medical assets and mobile equipment in your hospital?	51.40	48.60	1.49	Yes	**6**
Do you feel there is a need for tracking and locating patients and assets in your hospital to assist in improving efficiency?	94.10	5.90	1.06	Yes	**1**
Are you satisfied with the current practice of tracking assets at your hospital?	28.60	71.40	1.71	No	**5**

Additionally, the first two questions from the fourth part of the questionnaire addressed current practice in healthcare, specifically on waiting time to be seen by a doctor and on short or no supply of needed medical equipment in hospitals. Table 5.4 shows the results for the question, 'On average, how long do patients have to wait until being seen by a doctor in your hospital?' supplemented by a coded repetition and percentage. Only 1 respondent (0.50%) answered 'Less than 10 minutes,' 53 respondents (24.1%) answered 'From 10 to 30 minutes,' 114 respondents (51.8%) answered 'From 30 to 60 minutes,' and 52 respondents (23.60%) answered 'More than 60 minutes.' The majority of the respondents (51.8%) answered 'From 30 to 60 minutes'; which the patients have to wait before seen by a doctor.

Table 5.4 Repetition and Percentages of responses to Waiting Period

Waiting Period	Repetition	Percentage %
Less than 10 minutes	1	0.5%
From 10 to 30 minutes	53	24.1%
From 30 to 60 minutes	114	51.8%
More than 60 minutes	52	23.6%

Table 5.5 shows the responses for the question, 'How often are emergency rooms in short supply or no supply of needed medical equipment?' with the coded repetition and percentage. 'Very often' received 51 answers (23.2%), 30 respondents (13.6%) answered 'Often,' 64 respondents (29.1%) answered 'Somewhat often,' 61 respondents (27.7%) answered 'Not often,' and 14 respondents (6.4%) answered 'Never.'

Table 5.5 Repetition and Percentages of responses to Question 3.2

Medical Equipment Shortage	Repetition	Percentage %
Very often	51	23.2%
Often	30	13.6%
Somewhat often	64	29.1%
Not often	61	27.7%
Never	14	6.4%

5.4.3 Responses on the Need for a Real-time tracking and Monitoring System for Patients, Staff and Medical Assets

The remaining nine questions all employed a 5-point Likert scale ranging from ‘Strongly agree’ (5) to ‘Strongly disagree’ (1), with an option for ‘Neutral’ in the middle. To answer these questions, the researcher sought to define the perceptions of the sample individuals about the main study statements, based on percentages and averages; then the tendency was identified based on the standard criteria, as explained in Table 5.6.

Table 5.6 Standard criteria for defining the sample individuals’ tendencies

Tendency	The Average
Strongly agree	5
Agree	4
Neutral	3
Disagree	2
Strongly disagree	1

This coding is implemented for the consistency in analysis of the responses is provided in Table 5.7. This table provides the basic statistics necessary for analysis using the code provided in Table 5.6. The combined average is very significant, with a result of 5 and a heavy weight of ‘Strongly agree.’ This was the main tendency of the group, and the group therefore has strong agreement on ‘the need for a tracking and monitoring system for patients, staff and medical assets.’ Additionally, all statements resulted in a ‘Strongly agree’ tendency. Most significantly, from the results of these nine statements there was agreement on Statement 3.11, which concerned tracking and locating systems to help improve performance and efficiency specifically in Saudi Arabia. This received the largest ‘Strongly agree’ response among all statements, at 77.3%. The second-best statement was 3.3, which discussed the ability of a tracking system to enable quick location of patients for scheduled treatments of procedures. This statement received 68.2% of responses as ‘Strongly agree’ and fared better than several other statements with higher ‘Strongly agree’ responses, due to its concentration in the more positive side of the spectrum of answers. The next most favourable response was for statement 3.8, that locating critical care equipment quickly will improve patient care and staff productivity. This statement received 69.0% of its responses as ‘Strongly agree’. Fourth was

Statement 3.4, which dealt with the ability of a tracking system to improve patient protection. This statement received 60.2% response of ‘Strongly agree’ and an average of 1.39. The lowest of all statements’ response for ‘Strongly agree’ was the already mentioned Statement 3.4 with 60.2%. This helps explain the tightness of responses, as Statement 3.6, which concerns the use of ID tags to increase verification accuracy of individuals’ status and access, received the largest amount of negative response; 7.5% replied with either ‘Disagree’ or ‘Strongly disagree’. The responses to the statements are outlined in Table5.7.

Table 5.7 Responses Concerning the Necessity of Using an Intelligent Healthcare System

Statement	Strongly agree	Agree	Neutral	Disagree	Strongly disagree	Average	Tendency
3.3 In case of implementing a patient tracking system, patients can be tracked as they move about the facility, enabling them to be quickly located for scheduled treatments or procedures.	68.2	23.6	5.0	0.0	0.9	4.51	Strongly agree
3.4 A tracking system will enable better protection for vulnerable patients by sounding an alarm when patients leave designated areas.	60.2	29.6	5.0	0.0	0.9	4.35	Strongly agree
3.5 Patient tracking system can help in preventing and eliminating human and medical errors, such as patient misidentification.	62.4	22.4	10.0	2.0	0.7	4.36	Strongly agree

3.6 ID tags for relatives and visitors will increase the accuracy of verifying the individuals' status and areas of access like maternity, ICU, etc.	72.0	13.2	6.0	5.0	2.5	4.43	Strongly agree
3.7 A tracking system will help the hospital detect who enters or leaves a controlled area and notes their ID, status and time of access.	75.0	11.2	6.0	4.0	2.6	4.48	Strongly agree
3.8 Locating life-saving and critical care equipment quickly will improve patient care and staff productivity.	69.0	25.0	2.0	3.0	0.0	4.57	Strongly agree
3.9 Updating staff with responsibility by a tracking system when beds, wheelchairs and other equipment are unavailable will allow for faster patient/room turnover and improve hospital overall utilisation.	68.0	21.3	6.2	3.5	1.0	4.52	Strongly agree
3.10 Tracking assets system will result in tighter asset control and lower replacement costs.	69.0	20.9	4.6	4.5	1.0	4.52	Strongly agree
3.11 A tracking and location patients and assets system in Saudi Arabia healthcare institutions will help in performance and efficiency.	77.3	17.3	4.0	0.0	0.9	4.69	Strongly agree

The lowest average (and least support) of 4.35 indicates that there were no statements even relatively close to the 'Agree' response as an average. These results based on the sampled individuals' opinions indicate an urgent need for the development of an intelligent healthcare system to monitor and track patients, healthcare providers, and medical assets and properties.

5.5 Discussion

Most of the outlined results helped to confirm and supplement various problems and deficiencies identified in the literature. The chapter on challenges in healthcare identified several of the recurring issues arising in Saudi hospitals, some of which the questions in the survey directly address. Resistance to change, in terms of an Information Technology system, was perceived to be an important threat, though this questionnaire has illustrated the diminishing impact such a force might have in reality.

Among the most prominent issues discussed in Chapter 2 is patient misidentification, which can be fatal and many have the potential to cause harm (ECRI Institute Patient Safety Organization, 2016). Moreover, more than 500 patients admitted through A&E resulted in misidentification that led to incorrect medications (Ponemon Institute, 2016). Also, in the UK, 42% of total incidents in the NHS were patient identification errors (NHS, 2013). Statement 3.5 addressed this problem, which received one of the lowest averages among all 'need for change' questions but still retained the high average of 4.36, and thus still qualifies as an overall 'Strongly agree' of the group's tendency. A combined total of 84.8% of respondents, as shown in Figure 5.7, answered 'Strongly agree' or 'Agree' to the statement, 'A patient tracking system can help in preventing and eliminating human and medical errors, such as patient misidentification;' combined negative responses only totalled 2.7%.

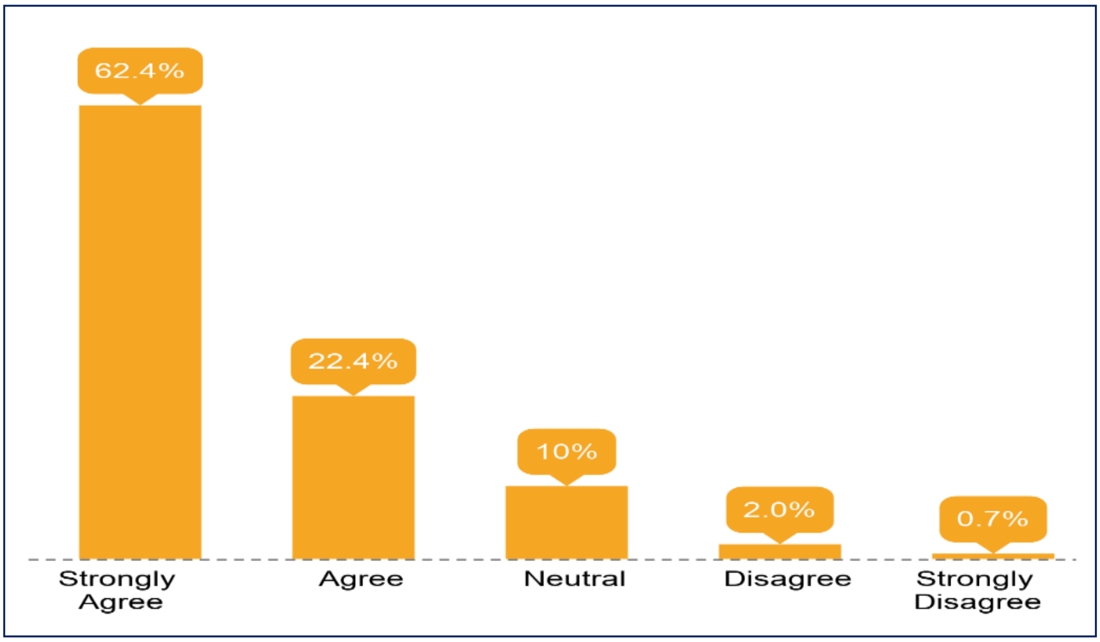


Figure 5.7 Can Tracking System help in preventing and eliminating human and medical errors, such as patient misidentification?

Opposition to change in this respect is therefore minimal, as there is heavy agreement among healthcare practitioners that a patient tracking system would assist in resolving the problem of patient misidentification. This statement encompasses other 'human and medical errors' as well, such as entering a patient address incorrectly or the inability to find a patient's medical record (Makary & Daniel, 2016; Ponemon Institute, 2016). Along these lines, Question 2.4, which asks about healthcare practitioners frequently misplacing or losing medical assets or equipment, resulted in 51% agreement as shown in Figure 5.8. Although this is the least significant aspects for part three of the questionnaire, it still identifies that more than half of respondents, all of whom are in healthcare positions, find this to be a problem. Also noteworthy is that the question using the phrase, 'very often,' means that respondents may have answered No if this was only an infrequent occurrence or if it only seemed to occur at non-critical times. The existence of this problem indicates the need for a long-term resolution, and RTLS provides answers, especially in terms of the locations and status of medical assets.

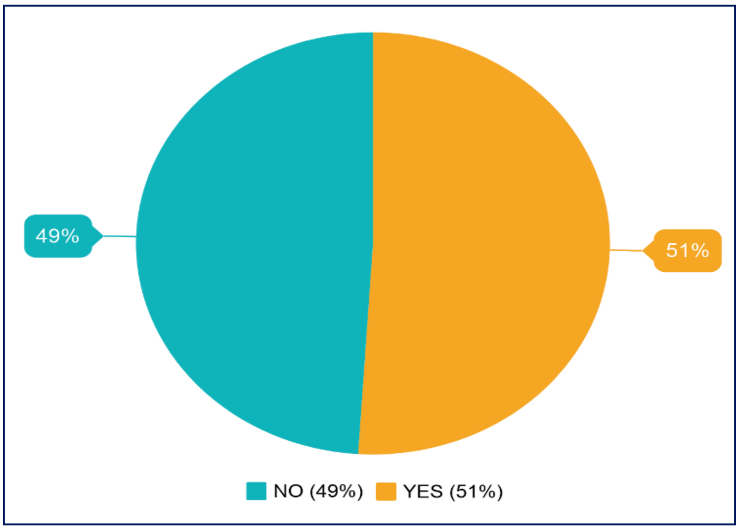


Figure 5.8 Do you have a difficult in misplacing or losing medical assets and mobile equipment's in your hospital very often?

The second major issue discussed in Chapter 2 is patient waiting time, something even more prominent in Saudi Arabia. This was recently reported to be 161 minutes for a patient to be a seen by a doctor (Mohebbifar et al., 2014), with 38.5% of people surveyed in Saudi Arabia agreeing that hospital visits take a long time (Al-Moajel et al., 2014; The Patients Association, 2016). Although much of reducing patient waiting is related to alleviating patient stress, improving their physical well-being and their relationship with the institution, the occasional life-or-death situations are the main reason for change. As demonstrated through Question 3.1 and shown in Figure 5.9, 75% of patients in Saudi Arabia have to wait more than 30 minutes to be seen by a doctor.

The comparison between the other statistics given in Chapter 2 remain deficient, however, the average waiting time in the U.S. was 24 minutes (Siciliani, 2014), and the responses outlined indicate that more improvements should be made. Furthermore, more than 70% of patients begin to feel frustration and anxiety after waiting more than 30 minutes (Al-Abri & Al-Balushi, 2014). Therefore, any result for Question 3.1 with a tendency of 'From 30 to 60 minutes' is subpar and not satisfactory. Improvements to this aim must be made, and efforts centred on using RTLS in hospitals can facilitate in the reduction of average waiting time.

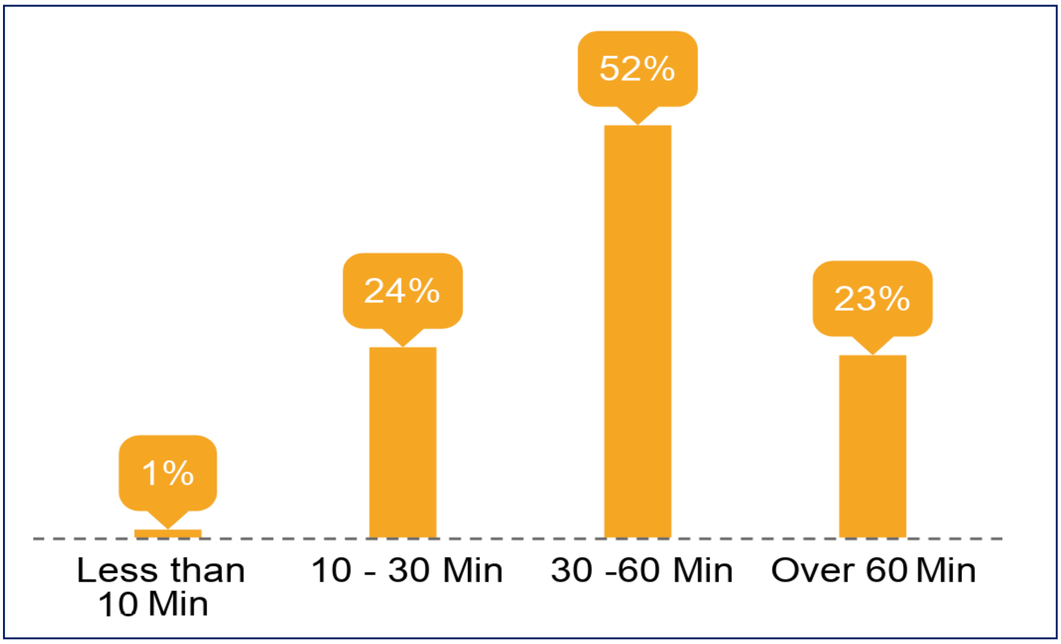


Figure 5.9 On average, how long do patients have to wait until being seen by a doctor in your hospital?'

Another issue discussed in Chapter 2 is patient flow; which corresponds with lower efficiency and effectiveness, higher costs, reduced safety, and more time and effort required from hospital staff (Ham et al., 2016; NHS, 2017). Improved patient flow leads to improved quality of care and productivity, and to improved efficiency. Many causes can affect patient flow and its management operation in hospital systems. One of the most basic questions to address this issue is Question 2.1: 'Can you track and locate patients and assets in your hospital?'. As shown in Figure 5.10 only 21% responded 'Yes'. This is a major cause for the lack of proper patient flow in Saudi hospitals. Without the ability to track or locate patients or assets within a hospital, time is lost searching for them. Additionally, statistics shows that clinicians waste an average of 28.2 minutes per shift due to patient misidentification, so that time is wasted, and optimal patient flow is impossible (Dooling et al., 2016). Of the 21% of respondents whose hospital has a tracking and locating system using manual tools, the nature of such tools was not clarified, nor the satisfaction with such tools linked with these respondents. That said, 29% of respondents claimed satisfaction with their current practice of tracking assets at their hospital, which could indicate that those respondents with tracking and locating systems were satisfied with the systems in place.

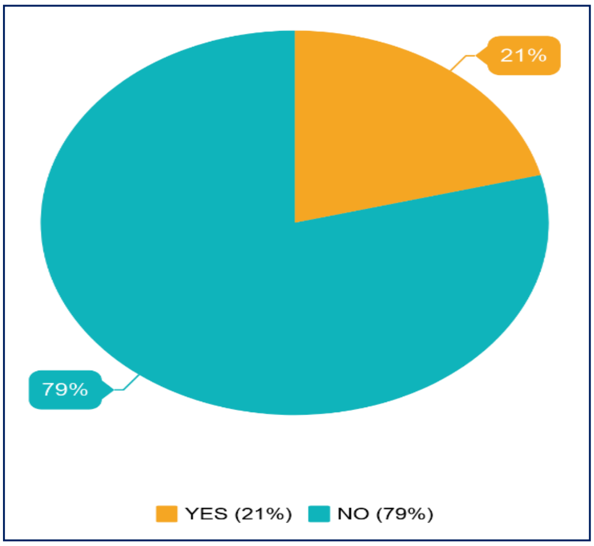


Figure 5.10 Can you track and locate patients and assets in your hospital?

Logically, there are respondents with no tracking system who are satisfied without it. There may be slight disparities in the interpretation of these two questions, as only 6% of respondents, as shown in Figure 5.11, do not feel that there is a need for tracking and locating patients and assets to assist in improving efficiency. This question (2.6) received the most overwhelming support, as 94% of respondents agreed that this was necessary, at least as it concerned efficiency.

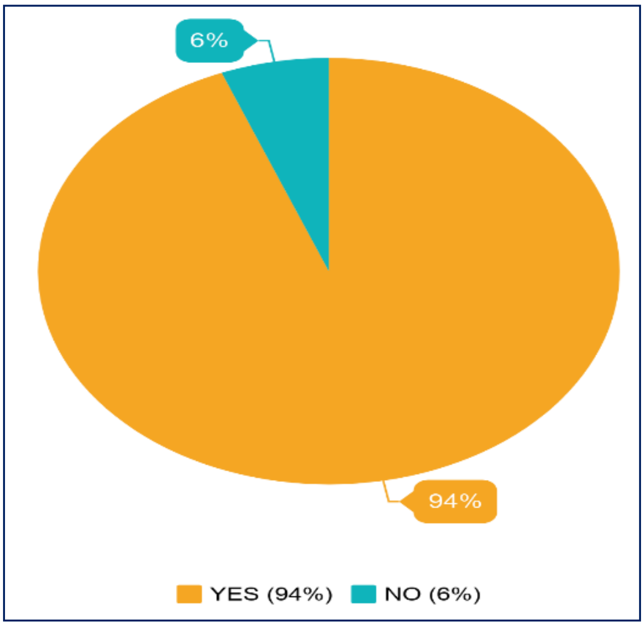


Figure 5.11 Do you feel there is a need for tracking and locating patients and assets in your hospital to help improving efficiency?

These three questions among the yes/no part of the questionnaire, all indicate a deficiency in patient flow in Saudi Arabia. As previously discussed, Question 2.4, which asks about misplaced and lost medical assets, similarly includes patient flow, as this can often mean that time is used to search for these devices/instruments instead of attending to patients' matters. There are a few statements in part three of the questionnaire that relate to patient flow: -Statement 3.3 (using a tracking system to quickly to locate patients for procedures), -Statement 3.9 (using a tracking system to increase turnover speed and improve hospital utilisation), and -Statement 3.11 (using a tracking system will help in performance and efficiency). In terms of combined positive responses (both 'Strongly agree' and Agree,') Statement 3.3 has 91.8%, Statement 3.9 has 89.3%, and Statement 3.11 has 94.6%, as shown in Figure 5.12. The similarity in response (which is roughly 94% for both Question 2.6 and Statement 3.11) becomes more revealing as they both concern hospital efficiency, with the former asking if the tracking system is needed, and the latter stating that it will help improve efficiency. Thus, those who believe such a system would help are likely to be in the same group of respondents as those who feel that there is a need for such a system. More important than this assumption, is the statistical finding that more than 90% of respondents both believe that a system would help in improving efficiency, and also feel a need for such a system for improving performance. As it is consistent with these results from the questionnaire, the effort to improve patient flow should be guided by and coupled with smart systems, such as the Real-Time Flow System (RTFS), which allows for the measurement of real-time flow, and for the ability to take action to maintain flow (Bean et al., 2017; Rutherford et al., 2017).

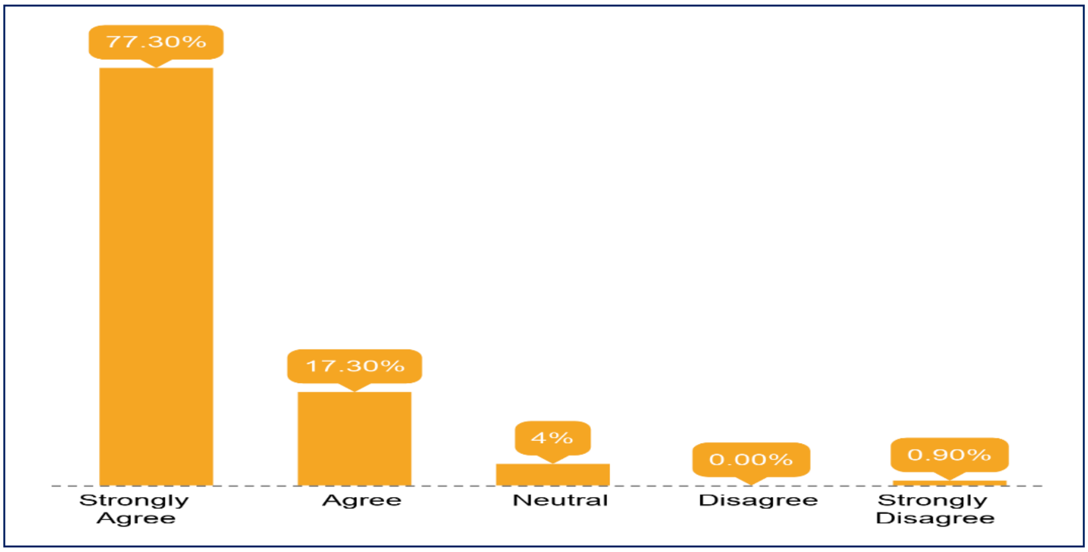


Figure 5.12 A tracking and location patients and assets system in Saudi Arabia healthcare institutions will help in performance and efficiency.

Many of the questions regarding patient flow also relate to the availability of medical equipment. In Saudi Arabia, a large portion of assets are lost, stolen or misplaced, which increases costs and reduces productivity. Theft of medical devices in 2016, at a single Saudi hospital, were estimated at £770,000 (Alkhatarsh & Alkadomi, 2016), compared with the entire UK NHS losing an estimated £13 million from medical equipment theft (Rossington, 2015). Although, this cannot be taken as an average theft rate for all Saudi hospitals, the fact that there were 470 Saudi hospitals in 2016 means that this order of magnitude could equate to £362 million in nationwide medical equipment theft, even though Saudi Arabia has roughly half the population of the UK. The ability to track and locate medical assets would therefore be a key differentiator in solving this major issue. This is re-confirmed by the following results:

- Question 2.1 indicated that 79% the lack of ability to track and locate medical equipment.
- Question 2.5 indicated that 71% are unsatisfied with current tracking practices.
- Question 2.4 indicated that 51% of respondents had difficulties in locating misplaced and lost medical assets.

The ability to be able to locate the medical equipment's location and status is currently beyond the scope of many Saudi hospitals, as evidenced by the low rate of ability to track and locate patients and assets, and the high rate of misplaced and lost medical assets. The shortage or lack of supply of medical equipment in vital situations, and the deficient ability to quickly locate critical care equipment are important requirements of the RTFS system. The majority of the respondents (66%) answered 'Somewhat often' or more frequently to Question 3.2, on the shortage or lack of supply of needed medical equipment, as shown in Figure 5.13. This helps explain the tendency of 2.80, which refers to the 'Somewhat often' response criteria as the tendency.

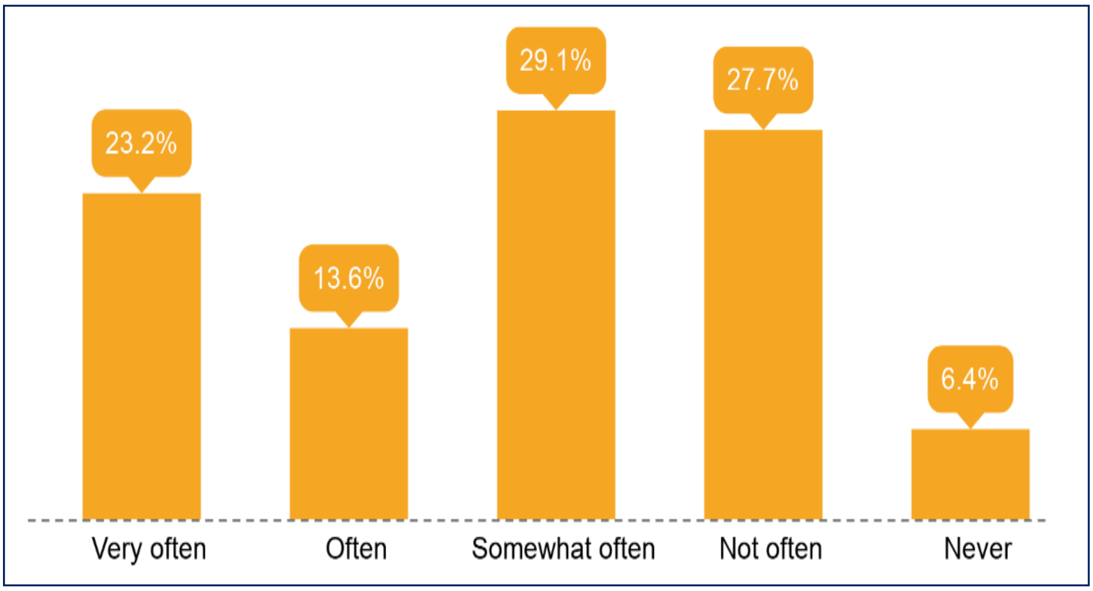


Figure 5.13 How often are emergency rooms in short supply or no supply of needed medical equipment?'

As this question concerns a time and place – the emergency room – of vital need and great urgency, the lack of availability of medical equipment is a significant reason by itself for adopting an improved system, which RTLS is capable of achieving. The tendency should be 'Never,' but this occurred with only 6.4% of the respondents. Besides having access to medical equipment, the immediacy of this information is much more important in healthcare, and is another need not being met in Saudi Arabia, as shown by the responses to Statement 3.8 (locating life-saving and critical care equipment quickly to improve patient care), and Statement 3.9 (using tracking systems for real-time status on equipment availability). For Statement 3.8, 94% of respondents provided positive answers, as shown in Figure 5.14, but it must be noted that this statement does not involve a reference to technology or to any kind of RTLS. It simply shows that the respondents believe the quick location of critical care equipment improves patient care and staff productivity. The means by which this quick location can occur is implied by the responses to the rest of the questions regarding tracking and locating systems. This is therefore a significantly positive response in favour of using a tracking and locating system for improving in locating medical equipment.

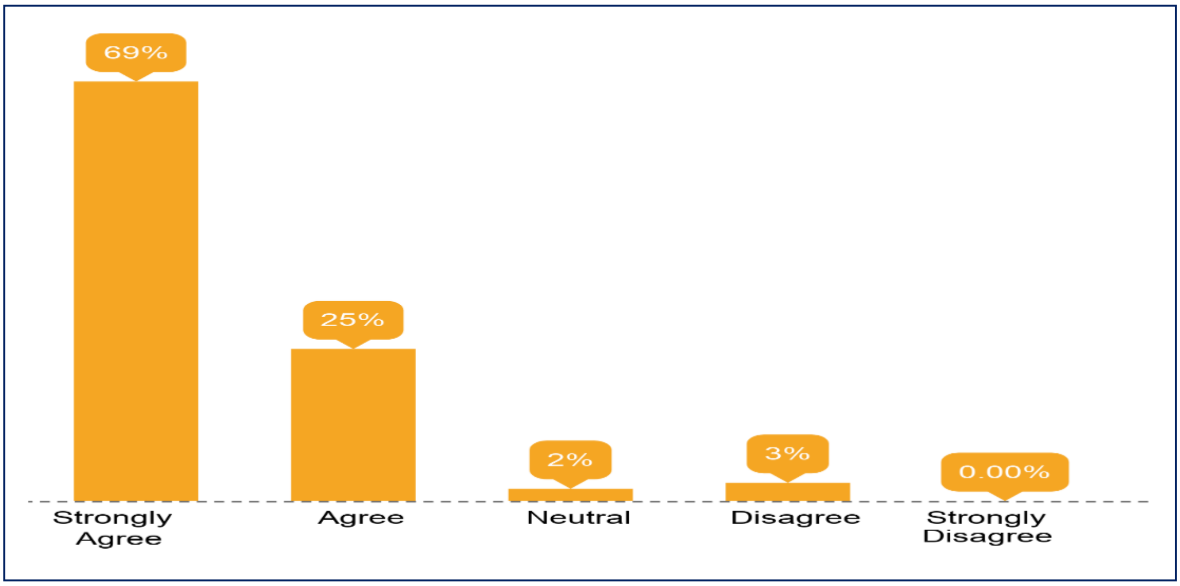


Figure 5.14 Locating life-saving and critical care equipment quickly will improve patient care and staff productivity.

Statement 3.9 states that 'Updating responsible staff by a tracking system when beds, wheelchairs and other equipment are unavailable or on shortage will allow for faster patient/room turnover and improve overall hospital utilisation'; 89.3% responded positively as shown in Figure 5.15. This statement concerns the proper utilisation of available medical equipment, which is even more importance when equipment is limited. This statement does implicitly include the phrase 'tracking system', which indicates acceptance of RTLS in improving equipment and room utilisation. This links with patient flow as previously discussed, and therefore interacts with multiple components of the hospital a series of complex systems.

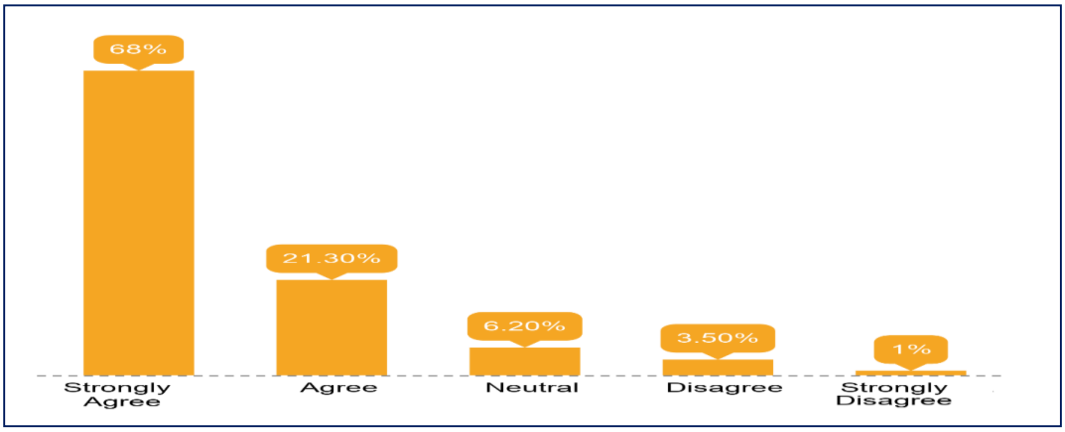


Figure 5.15 Updating staff when equipment are unavailable will allow for faster patient/room turnover and improve hospital overall utilisation.

Patient care and hospital staff productivity are highly interrelated, as suggested by questions that use one to imply the other. For instance, Statement 3.8 reads, ‘Locating life-saving and critical care equipment quickly will improve patient care and staff productivity.’ This connection is important for healthcare practitioners to notice, as the improvement of one likely coincides with the improvement of the other. In terms of general agreement (summing ‘Strongly agree’ and ‘Agree’), Statement 3.8 received 94.0% agreement, slightly behind Statement 3.11 with 94.6% agreement. The respondents therefore highly concur that the ability to quickly locate important medical assets is a significant factor in improving patient care and staff productivity. A solution to this deficiency would improve patient care by allowing staff to utilise any needed medical equipment without wasting time searching for it, and it would also improve staff productivity, by eliminating search time. According to Kattuah (2013), training is critical in improving staff productivity, which is why proper training is given such great attention in the framework developed in response to the results from this questionnaire (Kattuah, 2013). Appropriate RTLS, combined with adequate training on the new system, would be a long-term solution to locating critical care equipment quickly. Similarly, Statement 3.10, which states that ‘An asset tracking system will result in tighter asset control and lower replacement costs,’ also relates directly to staff productivity. A total of 89.9% of respondents agree that this statement is true, as shown in Figure 5.16, so this is another point of consensus. Tighter asset control implies real-time knowledge of asset location and status, in order to improve efficient utilisation of the organisation’s assets. Efficiency is directly correlated with productivity as well. Roghanian et al. (2012) defines productivity as a measure of effectiveness (‘Doing things right’) and effectiveness (‘Doing the right things’), with productivity being the sum of the other two (Roghanian et al., 2012). An efficient tracking system is therefore a logical solution to improving staff productivity.

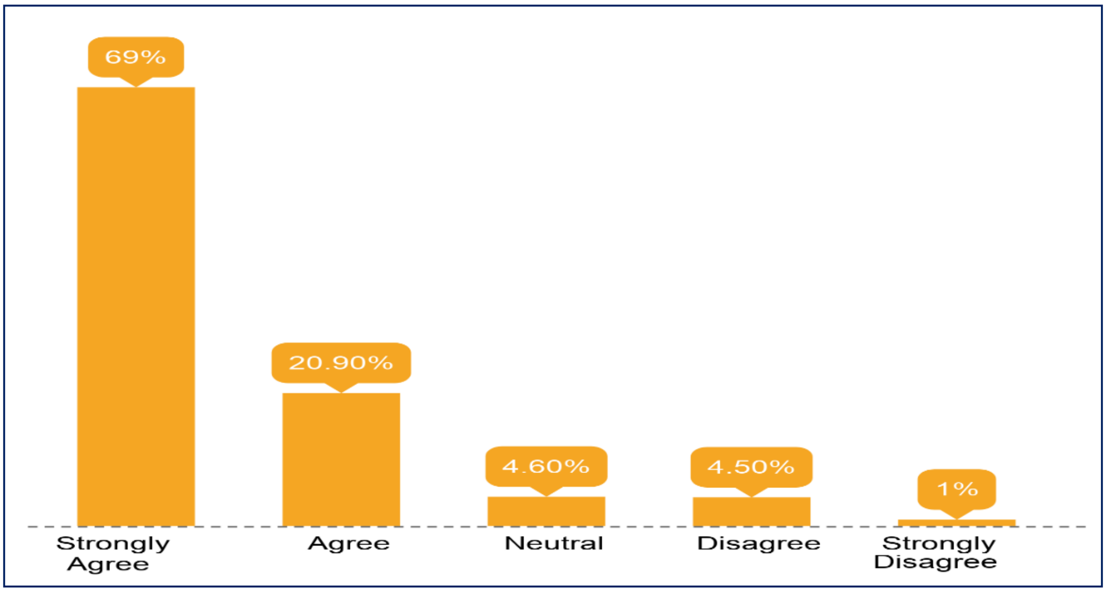


Figure 5.16 An asset tracking system will result in tighter asset control and lower replacement costs

Returning solely to patient care, a total of 89.8% of respondents agreed that 'a tracking system will enable better protection of vulnerable patients by sounding an alarm when patients leave designated areas.' There is, therefore, consensus on the use of a tracking system to improve patient care, as the alarms produced would ensure that unstable patients, such as suicidal or dangerous or dementia patients, remain within their areas, as designated by hospital staff. Finally, the simple question, 'Is there a system in place to measure staff productivity in your hospital?' revealed a severe deficiency among the respondents, of whom only 12% replied 'Yes' as shown in Figure 5.17. Without the ability to measure productivity, the processes and systems that constitute a healthcare organisation will have much more difficulty in improving. Patient safety and hospital security are addressed in several questions in the survey, and indicate problems in Saudi hospitals. Jo (2014) suggests utilising new technologies and automated safety checks to improve patient safety, while simultaneously addressing the problem of patient misidentification.

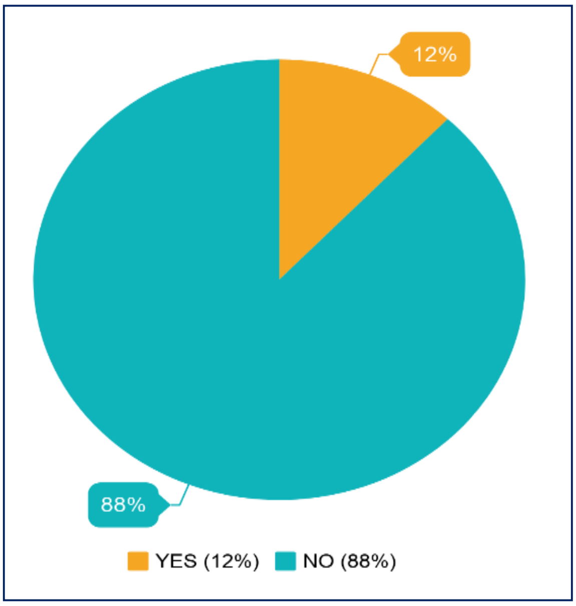


Figure 5.17 Is there a system in place to measure staff productivity in your hospital?'

Recently, in Saudi Arabia, 7% of hospitals received an Overall Patient Safety Grade of 'failing or poor,' Many of the areas with potential for improvement could easily be fixed with RTLS: under-reporting of events, non-punitive response to error, and collaborative staff groups across hospital units (Alahmadi, 2010). A tracking system would ensure greater accountability of hospital staff, and, therefore, increase reaction to errors in patient safety. For this questionnaire, three-quarters of the respondents (75%) did not yet have a method in their hospitals to verify an individual's access to certain places in their hospital. Furthermore, there was significant agreement among the respondents that a tracking system would prove invaluable in solving various issues related to patient safety. As shown in Figures 4.18, 85.2% of respondents agreed that 'ID tags for patients' relatives and hospital visitors will increase the accuracy of verifying the individual's status and areas of access.' Tracking visitors improves the hospital's accountability for keeping its patients safe and also assists in restricting visitors from entering places where they are not allowed.

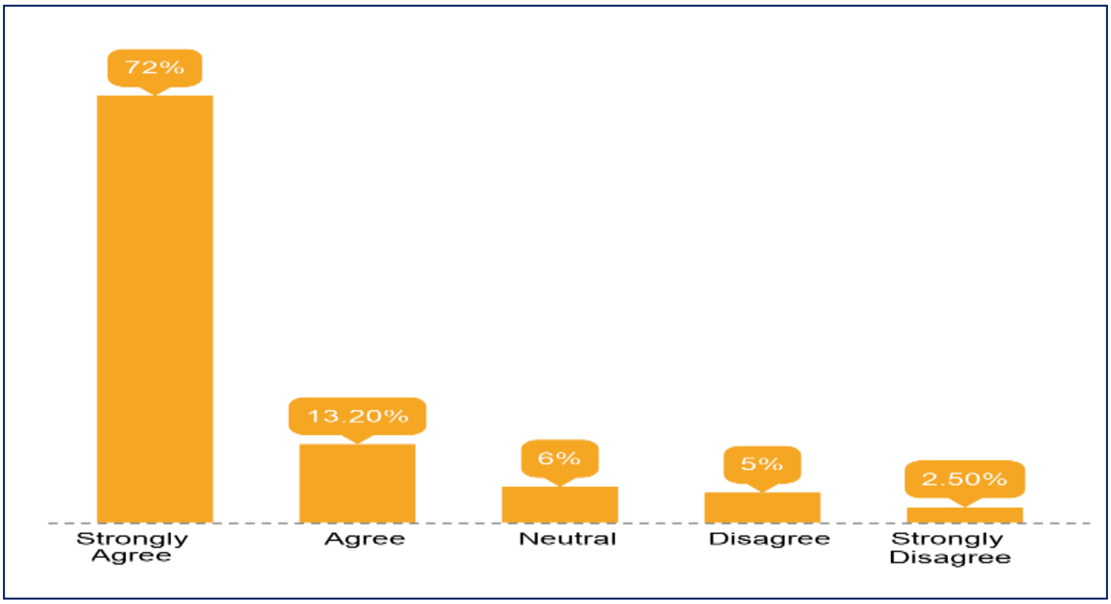


Figure 5.18 ID tags for relatives and visitors will increase the accuracy of verifying the individuals' status and areas of access like maternity, ICU, etc.

Similarly, 86.2% of respondents, as shown in Figure 5.19, agreed that 'a tracking system will help the hospital to detect who enters or leaves a controlled area and notes their ID, status and time of access.' This statement refers more to hospital staff, with location restrictions still in mind, but also raises hospital accountability and improves general security measures. A tracking system would be a solution for reducing to zero the number of hospitals with failing patient safety grades.

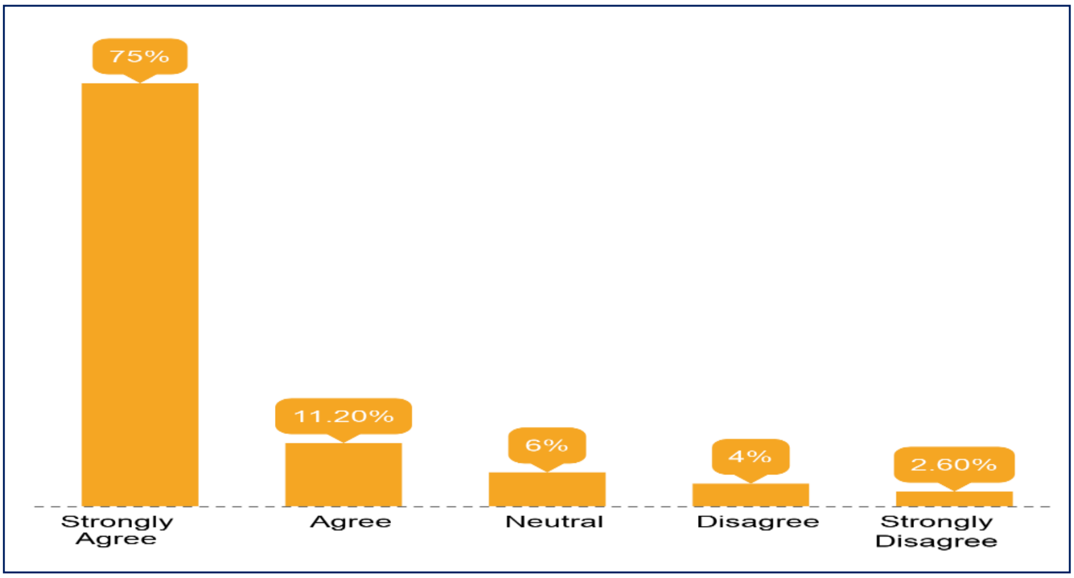


Figure 5.19 A tracking system will help the hospital detect who enters or leaves a controlled area and notes their ID, status and time of access.

In general, the questionnaire indicated a definite lack of proper tracking and locating system in Saudi hospitals. This is best demonstrated by the results regarding current practices, with 79% of respondents lacking the ability to track and locate patients and assets. The respondents were similarly dissatisfied with current practices and agreed with overwhelming consensus that a tracking and locating system was necessary. Based on the significance of the statistical tests and combination of dissatisfactory current practices and support for a tracking system, the questionnaire confirms the need for RTLS.

5.6 Refinement of the Holistic Framework (3rd Version)

The questionnaire confirmed the findings of the research as refined by the CoP and outlined in Chapter 4 (Figure 4.11) and brought to light more factors for use within the holistic framework. Based on the analysis provided in the previous section, two factors were added to the framework for a second refinement.

Within the human context, the questionnaire revealed that the "*user needs*" of the health information technology system are of importance for the consideration of an appropriate system. As healthcare organisations are of varying size and scope, they will be at varying efficiency levels. From the discrepancy between optimal and current productivity levels comes the established user need for the organisation. For example, an organisation with passing patient safety grades can perhaps continue their current practices while placing focus on technologies that excel elsewhere. User needs also relate to the comparison between current and required technological competency for both staff and patients: in an area with higher levels of education and technological advancement, it may be assumed that the system implemented can be more complex. This factor was derived ultimately from the demand to determine an element that encompassed the human factor of technology that related to technical competency as well as the needs of the organisation when disaggregated to the individual level.

Within the organisational context, organisational *availability* was added, as this requirement is evident from the questions on future needs. This factor asks the organisation several questions, one of which exists in the survey relating to those questions concerning the availability of medical equipment. Organisations for which medical equipment is readily available and accessible (i.e., within the room it is needed) may not need to consider improving this aspect in future technology adoption, but it may be a critical factor in organisations that are inefficient and inadequate in patient care. This factor also considers the availability of technology to the organisation, such as what is in-budget, but also what specific technologies are available to the organisation. This is determined by organisation location(s), size, nature of suppliers, time of analysis, and other factors.

Strong agreement was shown on all questions on the need for a health tracking and monitoring system, so the other factors were not adjusted as the questionnaire did not refute any of them. The final version of the holistic framework is shown in Figure 5.20, with the final version illustrating the inclusion of all refined contexts and factors.

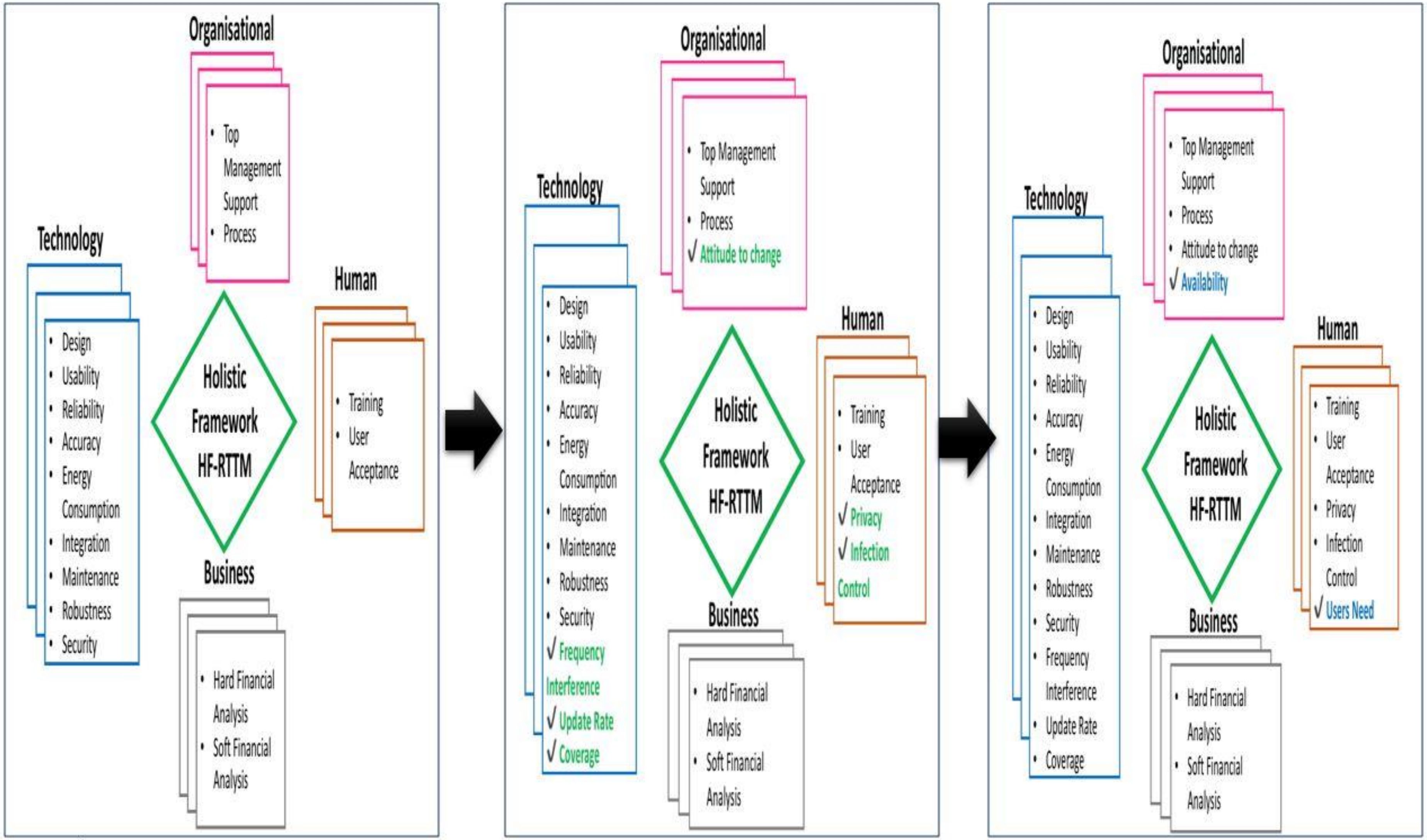


Figure 5.20 The final version of the development of the holistic framework

5.7 Conclusion

This chapter documented the design and implementation of a questionnaire-based survey for assessing the opinions of potential stakeholders about the relevant present situation in Saudi hospitals, and the need they feel for a real-time tracking system The survey results indicate a very high level of consent that implementing a real-time tracking system would help in solving many present problems, particularly by tracking patients as they move about the healthcare facility, thus enabling them to be quickly located for scheduled treatments or procedures. The analysis also reveals that implementing a real-time tracking and locating system for patients, staff and assets will increase performance and efficiency for healthcare decision support in healthcare institutions in Saudi Arabia. Further refinement of the holistic framework has been achieved through the addition of three factors based on the survey results. The assembling of a set of qualified and experienced people answering the questionnaire will also be useful as a source of possible future information and advice. With a refined framework in place, attention now turns to implementing these concepts in practice through improved workflow and aspects of simulation. The next chapter is devoted to hospital workflow improvements and simulation, with two trial experiments as proof of concepts.

Chapter 6 Hospital Workflow Improvement

6.1. Introduction

Utilising the third version of the holistic framework as refined by the CoP in Chapter 4 and by the questionnaire results in Chapter 5, focus can now turn to practical implementation of the system. This refined framework has to help the need of an effective and efficient healthcare services, with improved innovation in the patient-centric processes. Recent research has showed that the adoption of new information systems in hospitals can leverage the process transformation and workflow improvement (American Medical Association, 2014; Almomani & AlSarheed, 2016; Care & Care, 2012). Improvements are therefore needed for Smart hospitals to become more efficient and productive in terms of time and resources, to accelerate throughput, to enhance patient safety and to improve outcomes. Workflow improvements require quantitative methods that involve the dynamic nature of the interacting processes and people in a healthcare environment (Vankipuram et al., 2011). Simulation scenarios are the methods adopted in this chapter for this purpose. Although, much effort has been given to the understanding of the needs of healthcare professionals and of the hospital environment, but the real movement of patients and assets must be simulated for the validation of the proposed framework. This chapter provides a technique for simulation-based hospital workflow improvement, and also performs two real time ZigBee experimental trials both in laboratory and the hospital.

This chapter is organised as follows. Section 6.2 discusses the workflow challenges facing healthcare in Saudi Arabia, appended by a discussion of the literature on workflow improvements at a global level. Section 6.3 addresses the simulation concepts utilised for hospital workflow improvement, including an overview of simulation, of the simulation software used for this study, SIMUL8, and of the applications of simulation in healthcare. The details of the hospital used to gather the simulation data is outlined in Section 6.5. Section 6.6 consisted of three scenarios addressing the simulation concepts utilised for the hospital workflow improvement in this research. The three simulation scenarios (6.6.1, 6.6.2 and 6.6.3) relate to current practice, and to the relocation of administrative staff, nurses and medical devices, respectively. The second part (6.7) enhanced the simulation results using a proposed system for hospital workflow improvements through an interactive platform using e-health concepts. This study uses the current out-patient visit workflow to develop solutions for workflow issues.

The last part of this chapter (Section 6.8) explores the influence that the proposed introduction of e-health would make to searching, locating and monitoring members of staff, medical devices, and patients. For this purpose, two experimental proof of concepts trials (Section 6.8) were performed in the School of Computing Research Centre (Staffordshire University) and at a Saudi hospital, respectively. Both experiments showed a dramatic improvement in the times required.

6.2. Hospitals Workflow Challenges

Workflow in hospitals has achieved some improvements from a variety of sources, which have arisen from operations management. Wickramasinghe et al., (2014) illustrated that, one source hospital workflow improvements is *'lean thinking'*, which aims to:

- Understand what the customer (patient) values.
- Remove waste to reduce lead time (patient waiting time and complete service cycle time).
- Create a culture of continuous improvement.
- Make data-driven decisions.

The analysis of workflow is a complex task due to the many interacting factors, individuals and devices (Wickramasinghe et al., 2014). Malhotra et al. (2007) in their study, divided each strain of workflow processes produced by individual activities, isolated the activities based on their importance, and then developed individual workflows (Malhotra et al., 2007). The complete workflow was formed after analysis of the relationship between each critical zone. The objective of Malhotra et al 's study (2007) study was to reduce medical errors, which is relevant in the Saudi context as it links with patient misidentification and chart errors (Dooling et al., 2016).

In Saudi hospitals, patient flow is the driving factor behind patient waiting times and patient satisfaction levels (Almomani & AlSarheed, 2016). As discussed in Chapter 2 and to the best of the author's knowledge, there have not been any defined patient flow policies and procedures in Saudi hospitals. This situation is responsible for the high patient waiting times, most recently estimated at 161 minutes in the Middle East (Mohebbifar et al., 2014) compared with an average of 24 minutes for U.S. outpatient clinics (Siciliani, 2014). One of the other major issues leading to long patient waiting times in Saudi Arabia, is an issue of physician tardiness, which was also discussed in Chapter 2. The relevant statistics outlined that more than 20% of physicians in Saudi tertiary care hospital arrived more than an hour late according to a study by the Clinic Management Department (2014), and the average late arrival of doctors reached 49 minutes in a study by Almomani and AlSarheed (2016). The outcome of physician tardiness is longer patient waiting times, chaotic patient flow, patient dissatisfaction and poorer patient care. It is estimated that resolving the issue of physician tardiness alone could reduce service time in clinics by up to 20% (Almomani & AlSarheed, 2016). Hospital workflow is also affected by the non-existent of processes for real-time tracking and monitoring of healthcare staff, patients and medical devices (Jones & Schlegel, 2014). This underlying factor, which is at the foundation of this research, leads to higher overall costs, dissatisfactory patient care and safety (Ham et al., 2016), more time and effort required by healthcare professionals (Rutherford et al., 2017), cancelled surgical procedures, and underutilisation of hospital capacity (Carter, 2016).

Workflow modelling is the action of modelling a process in terms of the sequence of activities (van der Aalst et al., 2010). Workflow modelling can be achieved through process simulation, which is a type of simulation supported by hundreds of commercial simulation packages (Khodyrev and Popova, 2014). These packages can provide simulation tools or can embed their simulation capabilities within a workflow management system.

6.3. Simulation in Healthcare

Simulation is defined as *'the use of a computer program to model a real-world system in order to validate decisions affecting the system'* (Concannon et al., 2007). It is best suited to help design or modify complex systems, which makes it appropriate for the analysis of a hospital setting. Although, simulation can be used to provide stress tests, such as simulating rare occurrences so that extremely negative outcomes can be handled in the future, the simulation used for this research is designed to approximate the average process times of each individual workflow.

The use of simulation in healthcare has grown exponentially since the 1980s, and its applications have grown more sophisticated, wide-reaching and easier to use (Concannon ete al., 2007; Eldabi et al., 2006). Mathews (2016) used simulation in an Intensive Care Unit (ICU), to examine patient flow for the improvement of ICU throughput and for the assistance in future capacity planning within the hospital. Bed reallocation reduced waiting time by 7.2% and increased the hospital's occupancy by 4%. Baril et al. (2015) studied how simulation could be used jointly with a business game, to run scenarios during the lean activity in operations management of a Kaizen event, which is a week-long group activity used for the identification and implementation of a significant process improvements. The result of this integrated process was a 74% reduction in patient processing times. This research also emphasised the need for collaboration between physicians, pharmacists, management and administrative staff, who are all thoroughly trained on the Lean principles as well as on how the simulation would be conducted. Oh et al. (2016) also used simulation, to redesign an emergency department with the goal of processing 80% of all patients within 3 hours from arrival. This goal was achieved through optimised process flow, proper resource allocation, and through reimagined operational policies. Additionally, the average patient length of stay was reduced in the emergency department by 30%.

SIMUL8 simulation software is a product of the SIMUL8 Corporation used for simulating systems with discrete process analysis. This program is used for planning, design, optimisation and reengineering of real systems. SIMUL8 allows for the creation of a computer model taking into account real-life constraints, capacities, failure rates, shift patterns, and other factors affecting the total performance and efficiency of the system being investigated. Through this model it is possible to test real scenarios in a virtual environment, such as a change in parameters affecting system performance or the verification by experiments of the proposed solutions for the selection of the optimal solution. A common feature of problems solved in SIMUL8 is that they are concerned with cost, time and inventory (Taylor et al., 2012).

The benefits of a simulation relevant to this study include its ability to provide insight on the best choice, to manipulate time periods, to understand the systems that will be affected by implementation of this new technology, to identify any unexpected problems, to determine the bottleneck and to visualise the plan. Some of the challenges of simulations include their complexity, which leads to the requirement of specialist knowledge, the difficulty of interpretation, and the time-consuming nature of simulation. The relatively simple understandability of SIMUL8 requires no specialist knowledge for using it. The visualisation of SIMUL8 makes interpretation much easier than in traditional software, and ideal for business decision support. The choice of simulation as well as SIMUL8 was therefore appropriate for this analysis.

6.4. Hospitals Workflow Improvement Approach

Many approaches exist for managing and improving workflow, such as observations and interview data (Malhotra et al., 2007), workflow modelling (i.e., through simulation), and operations management principles (i.e., lean thinking, business process modelling, Business process re-engineering) (Murman, 2012; Samaranayake, 2015).

As shown in this chapter, simulation scenarios highlight the present issues in Saudi hospitals, for the purpose of contrasting current practices and capabilities with the performance of the proposed real-time tracking and monitoring (RTTM) system. Simulation scenarios are applicable to the proposed workflow improvement, as it can model the data provided by a real-time tracking and monitoring system that gather its data from RFID and ZigBee tags.

The first step is simulating the present conditions (as shown in Section 6.6), as a real environment for comparisons, which allows also for the validation of the real-time tracking and monitoring system intended for implementation in a similar environment. The number of staff, patients and assets can be modelled through the simulation, and their movements approximated through iterative runs. Each step of the patient processing cycle can be timed, to determine areas for future improvements. Therefore, this application of simulation through the modelling of real parameters helps to define the issues that are plaguing the organisation, such as the most significant workflow bottlenecks. For example, if simulation estimates that the average waiting time for patients to see a doctor reaches a peak at a certain time in the afternoon, improvements should focus on this time. Another example: if the real-time tracking and monitoring system indicates a shortage in the number of attending nurses or physicians, then the simulation features can propose a staff relocation, and calculate the optimal solutions to overcome this shortage instantly.

By developing the simulation model, it became clear to the researcher that:

A. The results of the simulation could be only as reliable as the data fed into it for the various activities and entities. Therefore, it was necessary to gather all the relevant data by hands-on surveys of a hospital typical of the KSA healthcare system. The researcher obtained full cooperation by such a hospital, as detailed in Section 6.5. Therefore, the method used for this research involved observation of a Saudi hospital environment, for the purpose of modelling, simulation, and performing proof of concepts trials experiments. These operations were conducted by the researcher, with the full support of the hospital. The next step in this approach was to meet with hospital staff, to gain insights on the processes that occurred in various workflows, such as patient schedules, the traditional patient visit flow, and practitioner processes (i.e., chart and data entry). Once this information was obtained, hospital observation was performed for the gathering of necessary data, used to shape the simulation parameters. Various scenarios were examined via a simulation platform (SMLU8), to determine the optimal solutions. A letter of support from the hospital is attached in Appendices A2.

B. It became clear that the simulation model being developed was abundantly flexible and powerful to allow, by simple adjustments, the study and optimisation of a multiplicity of situations and problems. Therefore, as well as applying it to analyse the proposed introduction of tracking and monitoring devices, (as shown in Section 6.7), the model was also applied to analyse simple organisational improvements to the existing facilities (administrative staff, nurses, devices, and physicians) that would produce considerable savings and better services (as shown in Sections 6.6.1 and 6.6.2 Scenario 2 and Scenario 3).

Section 6.7 covers the simulation of the hospital after the introduction of the proposed e-health system. The corresponding improvements are garnered from several sources through RTTM system, most important of which is the relocation of staff, patients or assets. The combinative relocation of all entities with tags, attached for real-time tracking and monitoring purposes, helps to maximise the benefits of the technology system. Generating solutions on where to relocate tracked entities comes from the identification of workflow bottlenecks over time and across functional roles, such as administrative staff or nurses. This identification is possible through simulation, as modelled in this chapter. Workflows can also be improved through the use of simulation of the RTTM system by insights on how to reschedule various events. This applies to staff, as certain roles (i.e., nursing at specific times throughout the day) may require more availability as determined by the simulation results; and when the organisation runs multiple facilities, reallocation of staff between facilities may become an optimal solution. Rescheduling of patients is most likely to be a simulation-derived solution, when physician availability becomes a bottleneck, or as determined by the capacities of facilities when they are a collective part of an organisation. Rescheduling of asset usage is also possible through the RTTM system, and simulation may provide insights on which pieces of medical equipment are used more frequently during a certain time by one part of the facility and more often by another part. Combining the two concepts of relocating and rescheduling, simulation provides in-depth insights on the reallocation of staff, patients and assets over time and across the organisation.

Details on the hospital that assisted the simulation are provided in the following Sections.

6.5. Background to the Hospital

The hospital chosen for this simulation study is one of the largest healthcare institutions in KSA with its 800 beds that serve an estimated 50,000 annual inpatients and 600,000 outpatients. It was established in 2004 and aims to lead the country in resource utilisation and training practices, which is the reason for such focus on its Information, Technology and Communications (ITC) department. ITC is responsible for implementing technological infrastructure that is both efficient and reliable. The department intends to achieve this through the transformation of Information Technology and Telecommunications into a digital platform alongside the creation of a strong IT team that could also deliver technical support to other MoH hospitals.

A new administration, called the Health Information Management (HIM) Administration, was also developed to meet demands for health informatics and to improve service quality for the patients. HIM oversees the departments of Information Classification, Release of Information, Information Management, File Management, and Eligibility and Registration. The departments are responsible for the following functions:

- *Information Classification*: improving analysis, verification, extraction, coding and reporting of data in healthcare;
- *Release of Information*: improving patient services and response time and accuracy of patient information;
- *Information Management*: improving automation of workflow and processes within the entire department;
- *File Management*: improving the integration and accuracy of patient records; and
- *Eligibility and Registration*: improving the coordination of cases transferred from other healthcare institutions.

6.6. Using Simulation for Hospital Workflow Improvements (1st Part)

Once the situation within the selected typical Saudi hospital environment was now known with a reasonable degree of confidence, the process of simulation could be approached. The concept of simulation will be overviewed with the software using, SIMUL8. The three scenarios simulated will then be outlined and the results provided to illustrate various aspects of workflows and process times supplemented with improvements derived from different scenarios and efforts reallocation.

The workflow of an out-patient traditional visit was outlined with the help of the CoP for the hospital as shown in Figure 6.1. Although the process may vary by organisation, the steps were agreed upon by the CoP for consistency and for testing purposes in this research as outlined below. The workflow process begins when the patient arrives and joins the queue for arrival registration. A member of staff will register the patient and send him/her to wait at the waiting area. A nurse then calls the patient to perform the initial check-up and the patient waits again to be seen by a doctor. After that, patients are either sent to the laboratory, pharmacy or x-ray for further examinations. Then, the patient will be returned to the reception to arrange a follow-up appointment. This is followed by the patient being discharged and checked-out by a receptionist.

This process can be divided into four workflow bottlenecks as follows:

1. Queue when arrived for registration.
2. Wait for vital signs to be checked by nurse.
3. Wait to be seen by a doctor.
4. Waiting for laboratory and pharmacy
5. Queue for follow-up appointment.

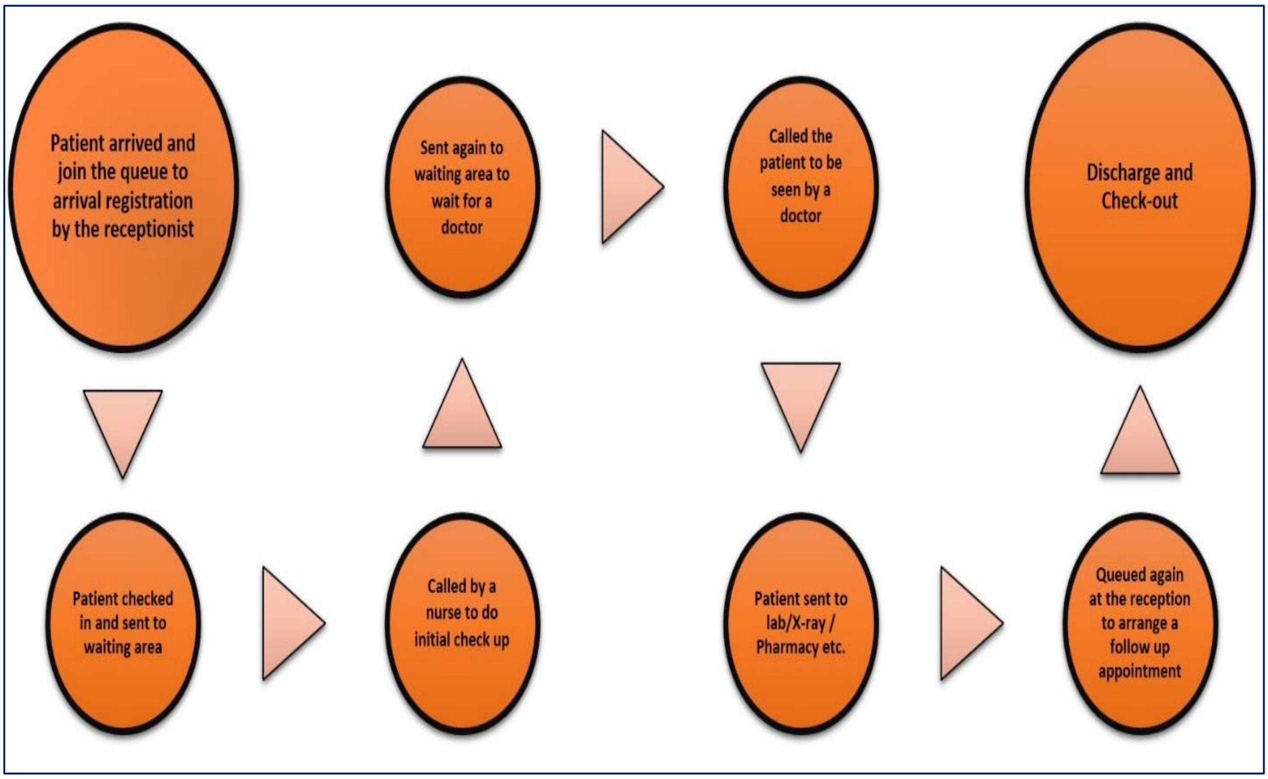


Figure 6.1 Traditional out-patient's visit flow

The average time spent currently per patient in each workflow bottleneck are shown in Table 6.1.

Table 6.1 Workflow bottleneck average times in current practice

Workflow bottlenecks	Average time
Queue for arrival registration	7 min
Wait for vital sign checking	5 min
Wait to be seen by a doctor	11 min
Queue for follow-up appointment	7 min
Total time	30 minutes

Figure 6.2 shows a screenshot of the simulation setting within the SIMUL8 application. The diagram shows the layout of a single floor of the hospital department with the locations of doors, walls, and rooms provided.

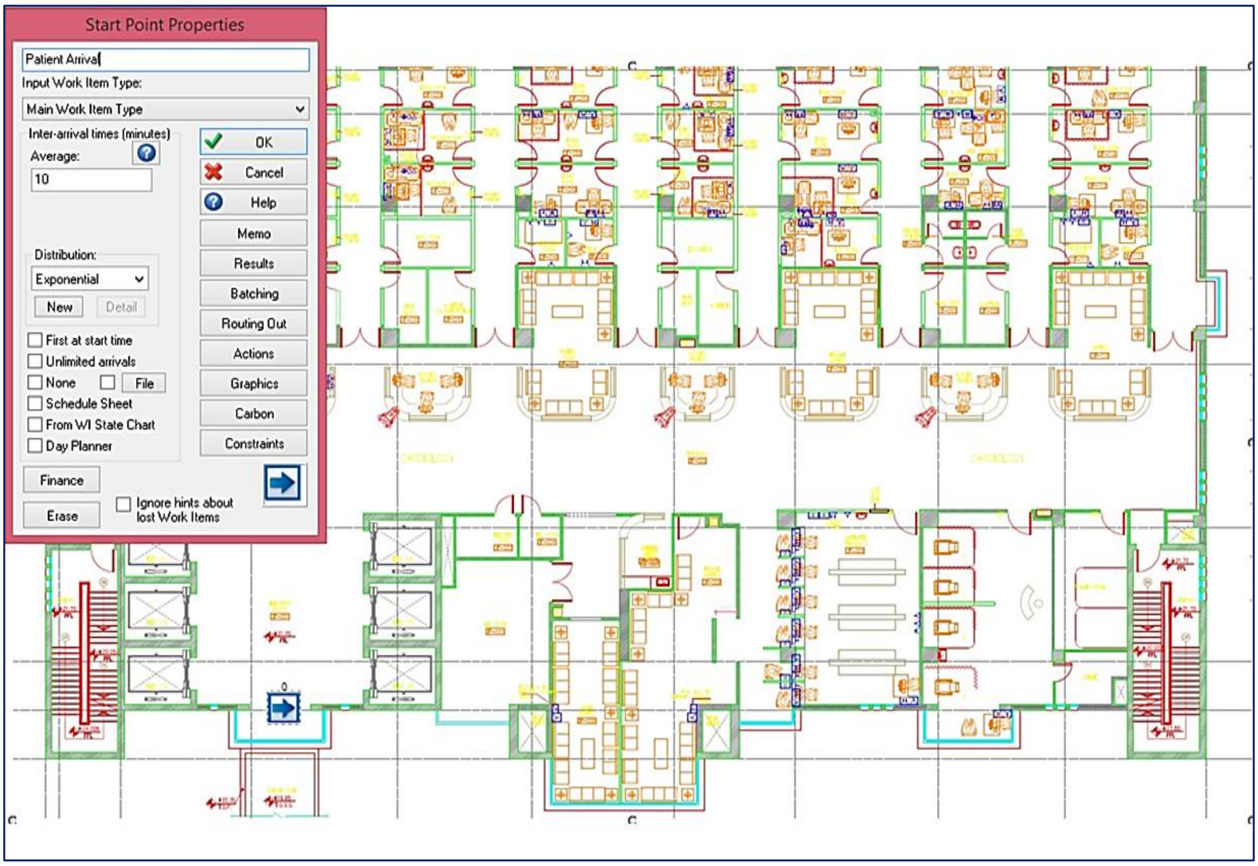


Figure 6.2 Simulation setting

The legend for the symbols used in the screenshots for the following scenarios is given in Figure 6.3, which outlines the building blocks of the simulation scenarios. In Figure 6.4 are shown the resources indicating the staff involved which are labelled as either receptionist, nurse, pharmacist, X-ray technician or doctor.

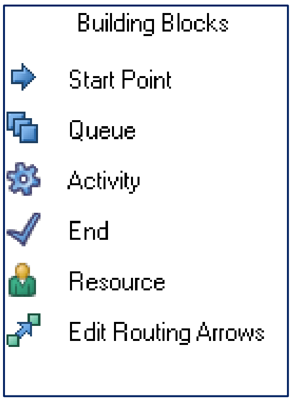


Figure 6.3 Legend for the Simulation

Using the operating procedures and placements of administrative staff, nurses and resources as discovered through the data gathered for the hospital and through discussion with the CoP, the current practice was found to progress as shown in Figure 6.4. The starting and ending points are located in the same area, with the patient approaching the reception for check-in and for check-out. The arrows follow the directions provided in Figure 6.4.

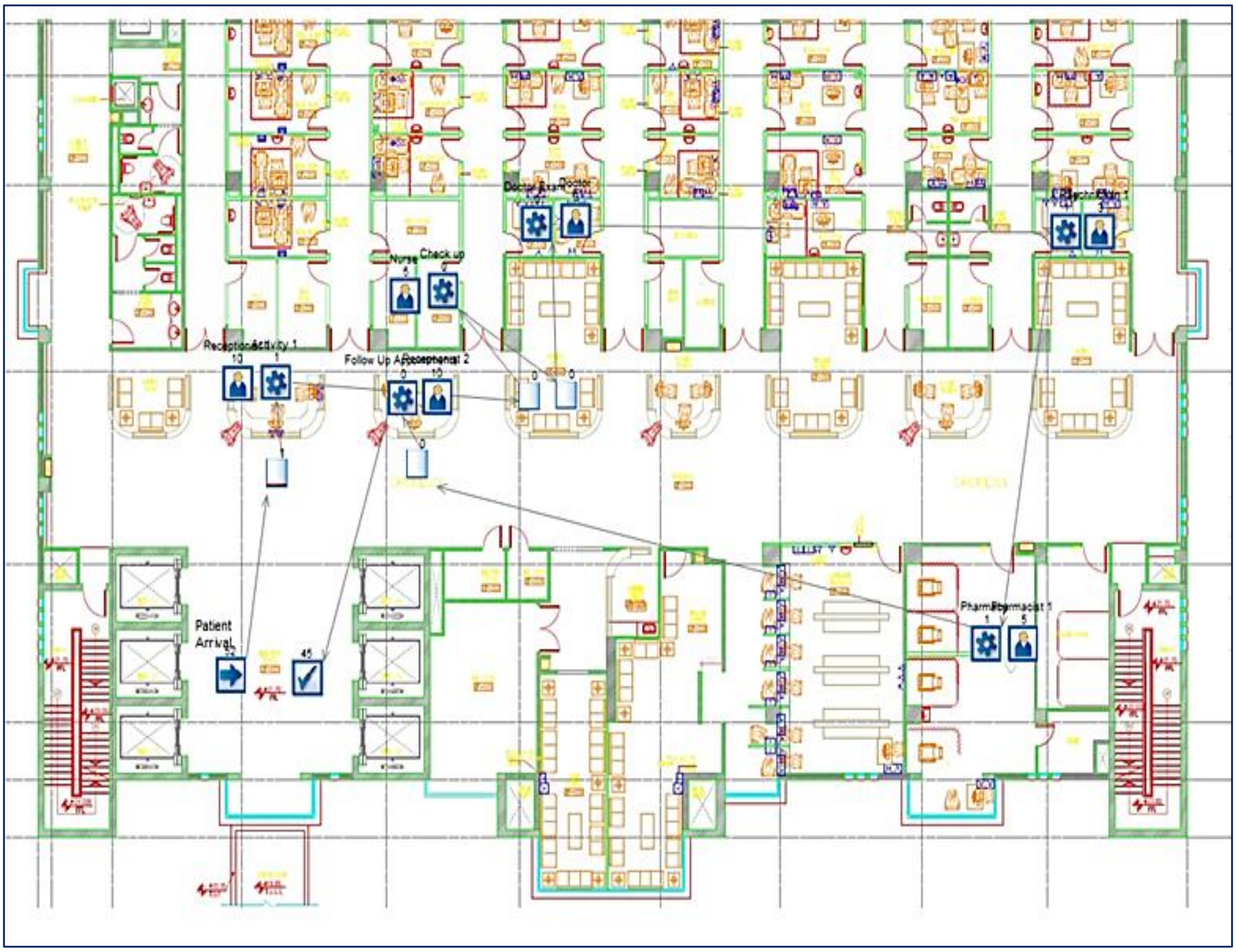


Figure 6.4 Current practice

The simulation scenarios were performed for the duration of an 8-hour workday and the results were determined in two ways. The first scenario result shown in Figure 6.5, which illustrates the variation in three primary elements: working time, waiting time, and blocked time while the activities are divided into nine stages. The result illustrates that the hospital is not fully utilising its capacity over time. An optimal view of this day would maximise the staff working period and reduce or eliminate the waiting time, and blocked time portions completely. The build-up of red portions in some of the workflow bottlenecks illustrates that the workflow can be improved by reallocation of resources such as nurses or receptionists. The simulation requires the entire process to be analysed, meaning that all nine stages must be considered when optimising for future improvements.

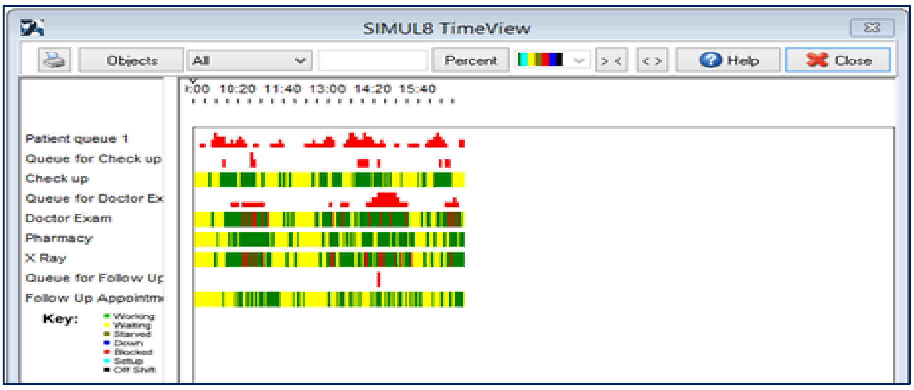


Figure 6.5 Simulation result of current practice

6.6.1 Scenario 1: Reallocation of Administrative Staff

The first scenario simulated the same environment with all building blocks represented in the legend remaining in the same locations except for the reception staff. This staff was relocated to different desks throughout the workday depending on the number of patients in the reception area. The 8-hour run-through produced the simulation platform as shown in Figure 6.6.

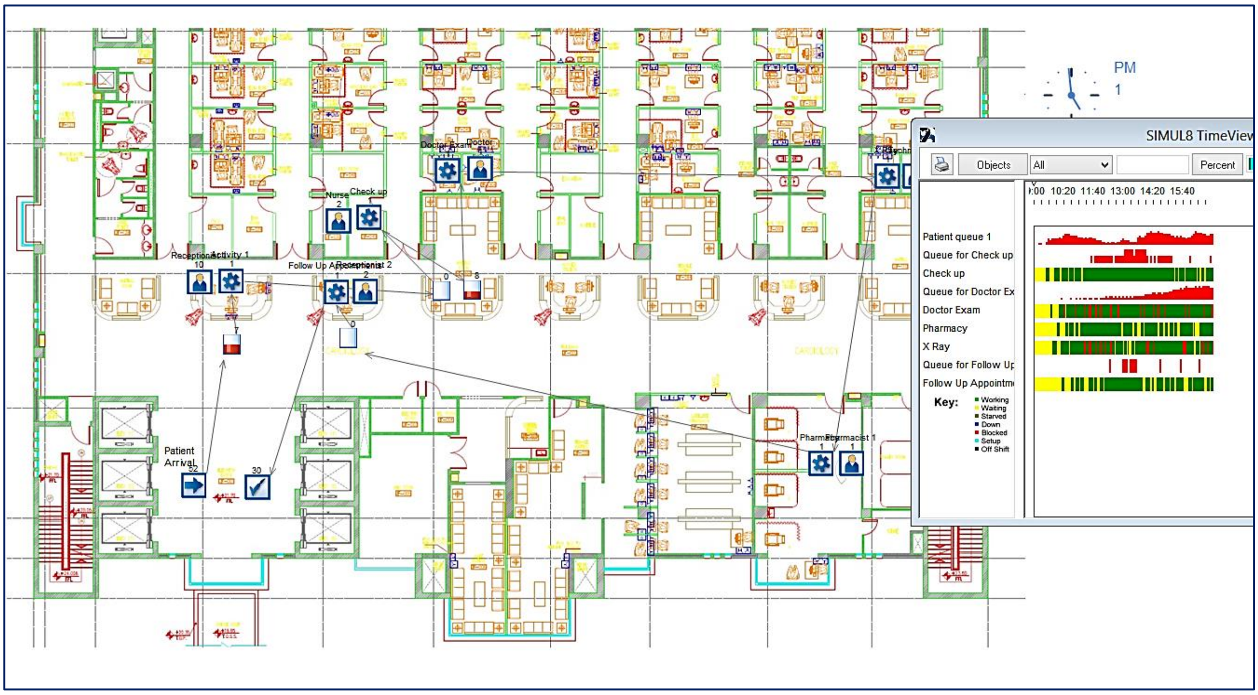


Figure 6.6 Simulation Result of 1st Scenario

The previous simulation result of current practice as shown in Figure 6.5 showed that the hospital is not fully utilising its capacity over time. However, the results in Table 6.2 show improvement in working periods which have been reflected in reducing the average time in this first workflow bottleneck (Queue for arrival registration) from 7 to 4 minutes and so on.

Table 6.2 Average Waiting Time of Workflow Bottlenecks for both current practice and 1st improved Scenario

Workflow bottlenecks	***Traditional practice***	***1st improved Scenario***
Queue for arrival registration	7 min	4 min
Wait for vital sign checking	5 min	5 min
Wait to be seen by a doctor	11 min	10 min
Queue for follow-up appointment	7 min	4 min
Total time	30 min	23 min

It is interesting to note that each average bottleneck time decreased so that the total patient waiting time was reduced from 30 to 23 minutes, an improvement of 23%. The simulation results were then improved by further scenarios.

6.6.2 Scenario 2: Reallocation of Nurses

The second scenario kept all variables the same as in the first scenario but relocated the nursing staff for better utilisation and to test for improvements in bottleneck times. The nursing staff were relocated according to the number of patients in each specified location so as to minimise the amount of time patients spent at in each workflow process. The simulation result in Figure 6.7 showing the number of activities during 8-hour workday. The diagram shows that more than 50% of the time is occupied by these activities and that they are still left unused for most of the remaining time.

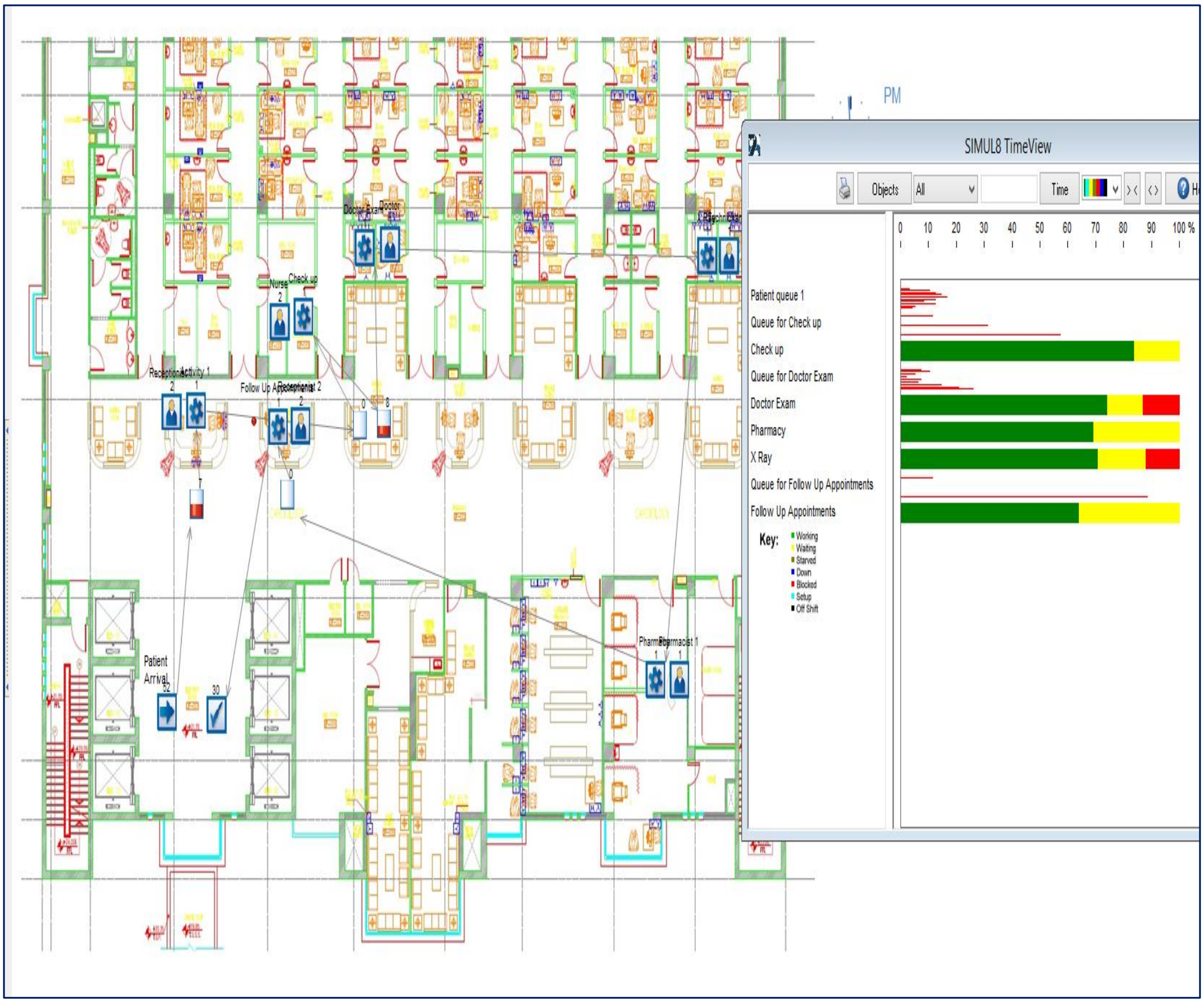


Figure 6.7 Simulation Result of 2nd Scenario

The results for average waiting time for each bottleneck activity are shown in Table 6.3. The results are identical to those of the first scenario except for those of the wait for vital sign checking and for being seen by a doctor, which have been reduced from 5 to 4 minutes and from 10 to 8 minutes respectively. This reduces the total bottleneck time to be 20 minutes, a 33% improvement from the current practice. The other workflow bottlenecks show the same average times.

Table 6.3 Average Waiting Time of Workflow Bottlenecks for current practice and, 1st & 2nd improved Scenario

Workflow bottlenecks	***Traditional practice***	***1st improved Scenario***	***2nd improved Scenario***
Queue for arrival registration	7 min	4 min	4 min
Wait for vital sign checking	5 min	5 min	4 min
Wait to be seen by a doctor	11 min	10 min	8 min
Queue for follow-up appointment	7 min	4 min	4 min
Total time	30 min	23 min	20 in

6.6.3 Scenario 3: Medical Devices Utilisation

The third scenario held all variables constant with respect to the first scenario except for those of resources such as medical devices, which were relocated based on insights provided by the hospital. The simulation result in Figure 6.8 show number of activities during 8-hour workday. One of the key findings here is the substantial increase in working periods for nurses and doctors after better utilising the medical devices which have increased from an average of 60% to a range between 80% and 90%. Utilisation is therefore much higher under this scenario, and bottleneck times are also better managed.

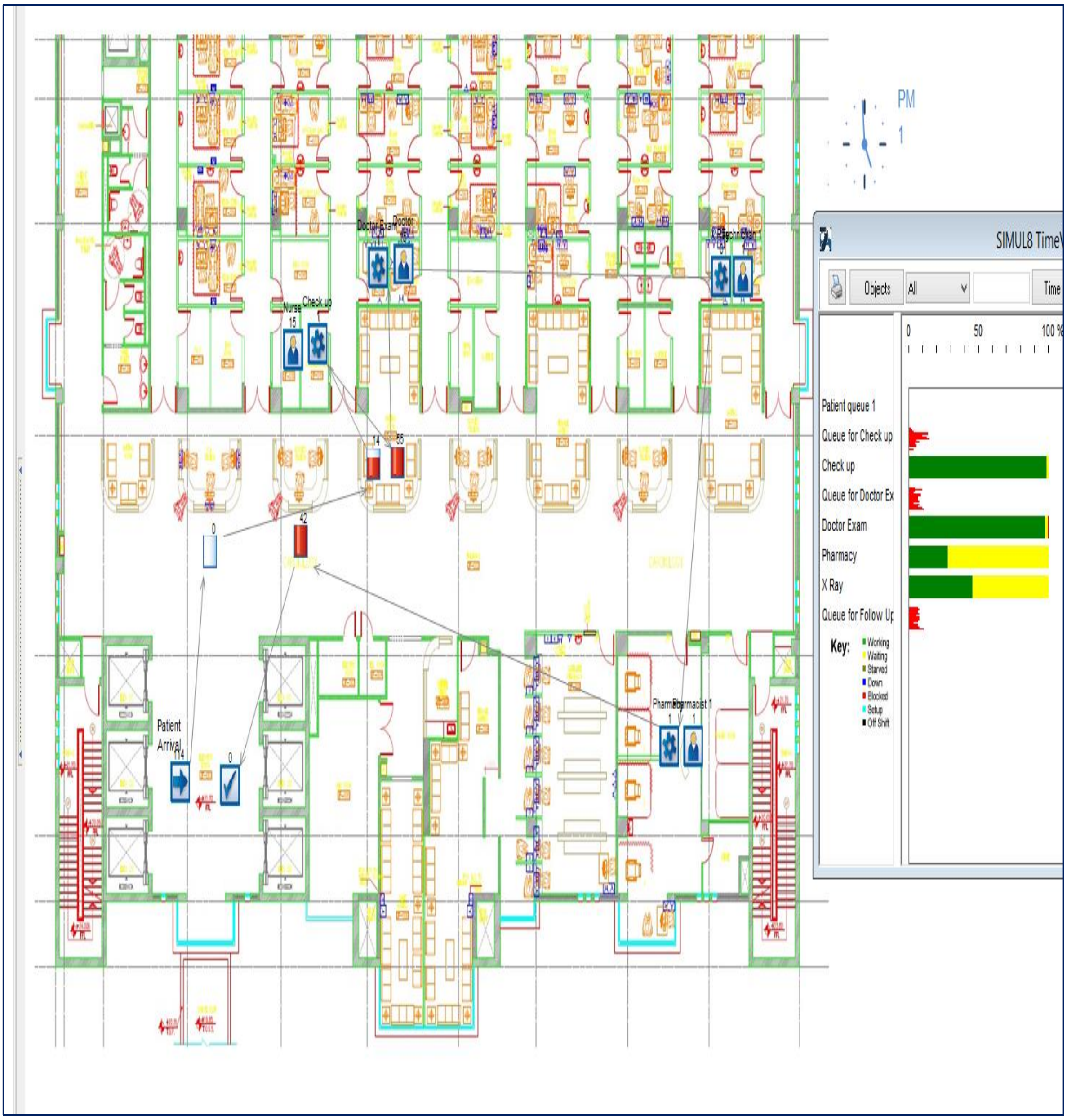


Figure 6.8 Simulation Result of 3rd Scenario

The results in Table 6.4 indicate that this scenario provides the lowest average bottleneck times for each waiting activity. The total average waiting time of 17 minutes is a 40% improvement on the current practice. Combined with the increased utilisation of nurses and doctors, this is clearly the best solution so far for reallocation of resources based on the simulation performed in this study.

Table 6.4 Average Waiting Time of Workflow Bottlenecks for current practice and, 1st, 2nd & 3rd improved Scenario

Workflow bottlenecks	Traditional practice	1st improved Scenario	2nd improved Scenario	3rd improved Scenario
Queue for arrival registration	7 min	4 min	4 min	4 min
Wait for vital sign checking	5 min	5 min	4 min	3 min
Wait to be seen by a doctor	11 min	10 min	8 min	6 min
Queue for follow-up appointment	7 min	4 min	4 min	4 min
Total time	30 min	23 min	20 min	17 min

6.7. Proposed improvement using e-Health System and Hospital Workflow Improvements (2nd Part)

Using a combination of the first through the third scenarios leads into an e-health system for hospital workflow improvements that, by using an interactive platform, substantially reduces all workflow bottleneck times. This requires an electronically managed system that facilitates patient registration and booking. Resources waste times can be reduced to their attainable minimum and staff can increase their productivity. Figure 6.9 shows the revised steps for the patient flow. The addition of a kiosk or of a mobile application (through which patients can register upon arrival, receive the electronic tracking tag and set up their follow-up appointment after being seen by the doctor), helps in improving the general workflow. This is achieved by alerting administrative and nursing staff with the location and status of patients, and improves the productivity of the doctors.

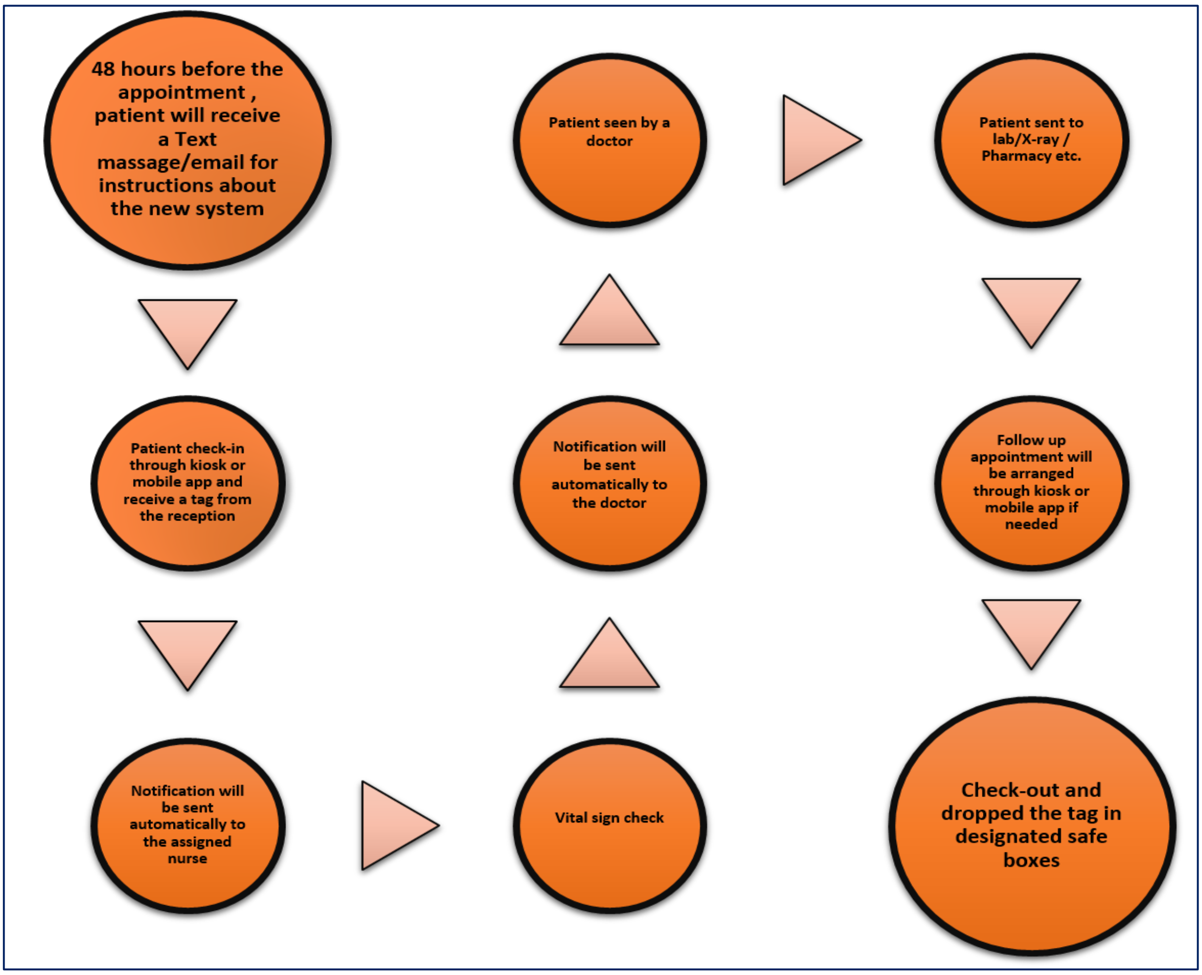


Figure 6.9 Proposed Steps for a New Patient flow

The simulation results in Figure 6.10 showed an optimised solution, with blockage periods distributed evenly throughout the day, ensuring that no patients wait for long periods of time, and maximises capacity. Nursing staff are utilised for more than 95% of the workday, meaning that the number of nurses scheduled to work can be adjusted according to this new strategy. Additionally, doctors are also utilised more than 90% of the time as well, which leads to a similar ability to improve scheduling. The enlarged proportions of yellow within the pharmacy and x-ray activities are desirable, because these activities are fixed spaces and resources that must be available whenever needed.

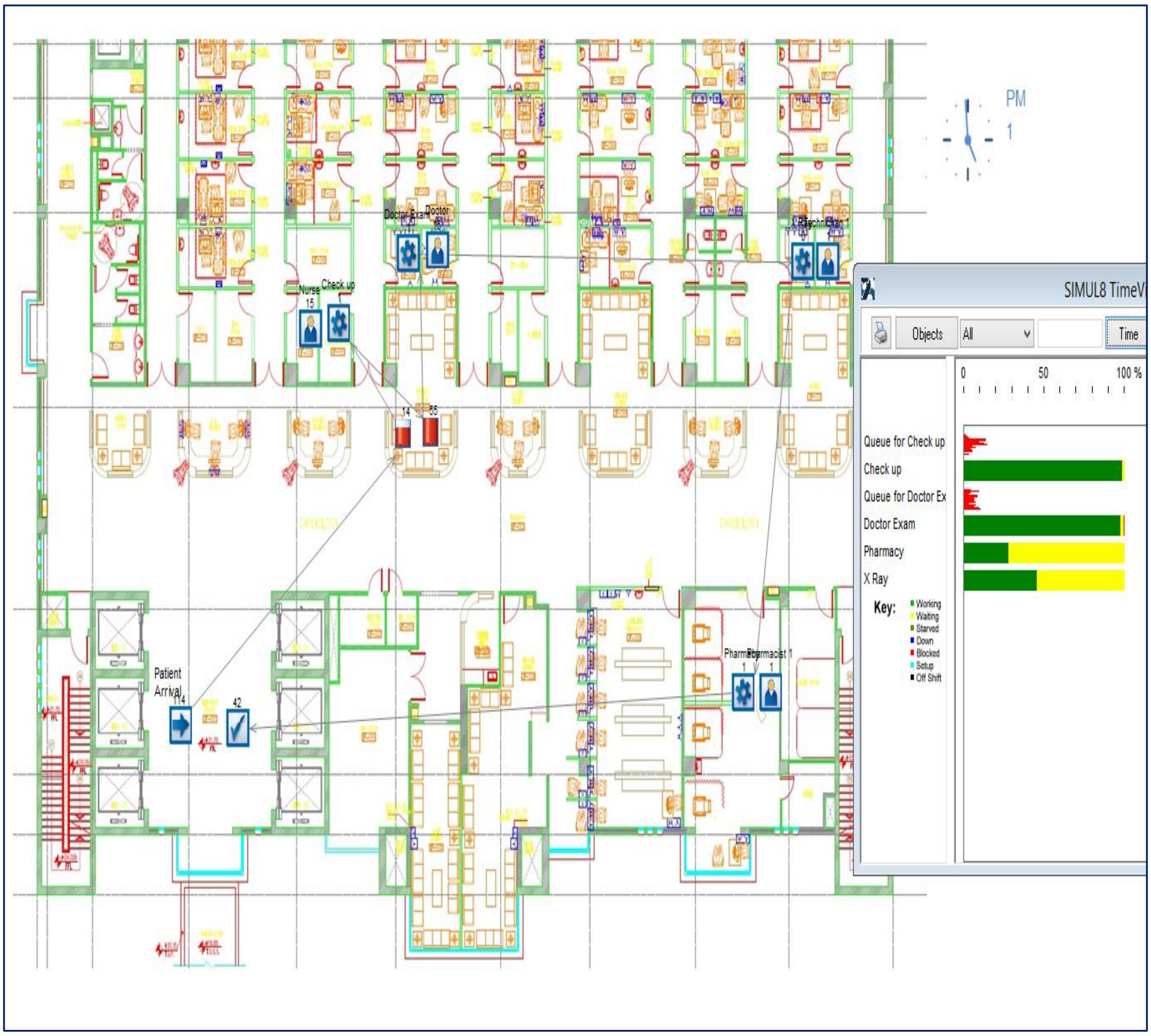


Figure 6.10 Simulation Result of Proposed New Patient Flow

In Table 6.5, all bottlenecks have been reduced after the relocation of the resources. Additionally, the total average bottleneck time has been reduced to 10 minutes, a 67% reduction from current practice. The e-health system is therefore significant in improving all waiting stages and in improving hospital performance.

Table 6.5 Workflow bottleneck average times for Proposed New Patient Flow

Workflow bottlenecks	***New System***	***Traditional practice***
Queue for arrival registration	2 min	7 min
Wait for vital sign checking	2 min	5 min
Wait to be seen by a doctor	4 min	11 min
Queue for follow-up appointment	2 min	7 min
Total time	10 min	30 min

Using the results from the simulation of the e-health system, a revised patient visit scenario can be constructed that incorporates the available technology. The primary change in the proposed enhanced e-health system is the use of a tag attached to the patient upon entry, which is returned to the hospital upon check-out, and the addition of a mobile application in which patients can check in and schedule their follow-up appointments. The first step begins by utilising the technology by automatically sending a text message or email to the patient 48 hours before their appointment with instructions about the e-health system and incorporating tagging that will be used for patient workflow improvements. These instructions consist of some form of educational tool, such as an interactive platform, for the patient to learn how to use the system and understand its benefits. This step will also provide a method, such as by an interactive two-way massaging through a mobile app, to contact the hospital to raise any concerns the patient may have before the visit.

The added benefit of the e-health system is the automatic notifications sent to the nurse assigned to a patient, which include an alert sent as soon as the patient has checked in and received a tag. This alert occurs again for the doctor, so that the e-health system provides the best results for this workflow bottleneck. At the end of the visit, the patient will receive a reminder via text or through the mobile application notifications, before returning the tag to a designated safe box and leaving the hospital. Although, passive tags are typically no more than $0.15, this reminder can make saving for the hospital, by keeping the tags in circulation.

6.8. Performance of Proof of Concept Experimentations and Results

The previous section determined the large improvements that the adoption of e-health would make to the workflow. However, a serious problem in hospitals is the difficulty to locate personnel, medical devices and doctors, as they keep moving to attend to the various duties that arise continuously in a hospital. Large amount of times are wasted for this reason and, much more important, delays in providing urgent services occur, with the possibility of dangerous situations arising. It is common sense that the introduction of the proposed RTTM system would be greatly beneficial for this problem, but it was felt that these benefits ought to be proved and quantified, in consideration of the expenses to be incurred and to the changes to staff working practices that would be involved.

This section explores the influence that the proposed introduction of e-health would make to searching, locating and monitoring members of staff, medical devices, physicians, and patients. For this purpose, two experimental proof of concepts trials were performed, one in the School of Computing Research Centre, and another one at a Saudi hospital. Both experiments showed a dramatic improvement in the times required for these purposes. Indeed, they resulted in the complete disappearance of the searching and location problems, since such actions became practically instantaneous.

For the two experiments performed, various real-time tracking and monitoring tools were analysed to match the aim and objectives of this study. The measured performance of ZigBee within the relevant setting of an indoor facility was needed in order to obtain general results on the improvements garnered from the implementation of such a system. The two trial experiments are detailed in the following Sections.

6.8.1 Laboratory Proof of Concept Experiments (1st Experiment)

For the experiment, the ZigBee components were as follows, with images of the component provided in Figure 6.11:

- 1 tag (type: n-Core Sirius D)
- 8 readers (type: n-Core Sirius Quantum)
- 1 coordinator (type: n-Core Sirius A)

Figure 6.11 System components for 1st Experiment, with tag (left), coordinator (right) and readers (centre and below)

The School of Computing Research Centre was used for the laboratory experiment, and its physical layout is shown in Figure 6.12. This location was used as it approximates to the typical size of a single hospital ward and provides separate rooms for which a non-line of sight technology must be able to handle.

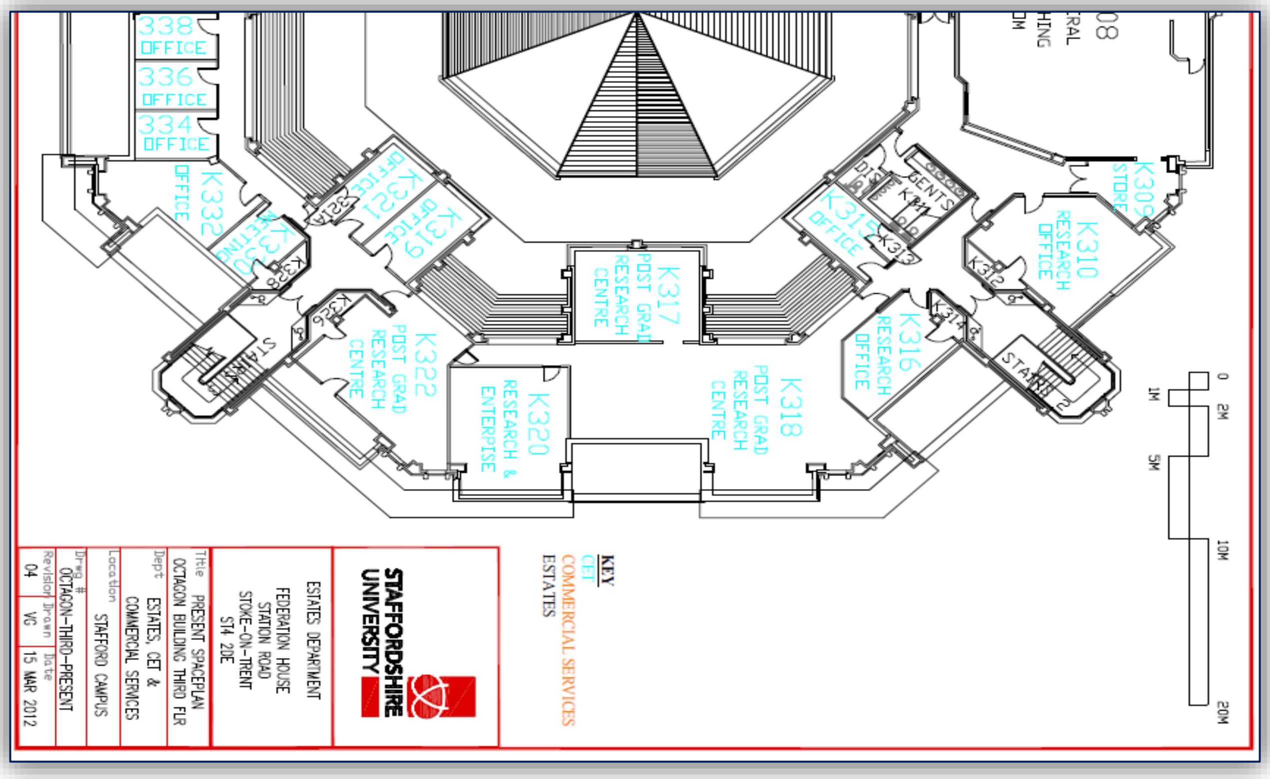


Figure 6.12 Research Centre Layout

The topology for the experiment was a Mesh network for the main communication link between the ZigBee readers. Mesh topology provides full connection for the network where reader and coordinator are located less than 10 metres from one another (Tapia et al., 2013). This is also the most likely method in a hospital environment, as it should be chosen based on its scalability, when many tags join the network. Personal Computer (PC) acted as a server for this experiment, as it did not require extensive processing power. The software platform used was Polaris n-Core, which is a web-based tracking system.

All objects requiring tracking and locating were attached with a ZigBee tag that communicates continuously via data transfer with the nearest ZigBee reader. As there were fewer than ten readers to set up and the time to set up each device required 5 to 10 minutes, the entire setup time was less than an hour. The tags were attached to a subject via wristband and the subject walked around the Research Centre.

6.8.2 Hospital Proof of Concept Experiment (2nd Experiment)

The experiment performed in the hospital in Saudi Arabia (introduced in Section 6.5) used the same ZigBee system components of the same types, but observed hospital staff and medical devices through 5 tags. Since an actual hospital environment was used, the time to decide the location of each device and perform setup ranged from 10 to 15 minutes. Examples of ZigBee system components are shown in Figure 6.13.

Figure 6.13 Placement of tracking and monitoring system components in 2nd Experiment

The distance between devices was chosen depending on the relation between them, while using the knowledge that the most accurate results come from devices within a radius of 25m from each other. For this circular area, only one reader and coordinator are required, and the number of tags is essentially as many as can fit within the space. Figure 6.14 illustrates how a single central coordinator and reader can span the reach of several tags.

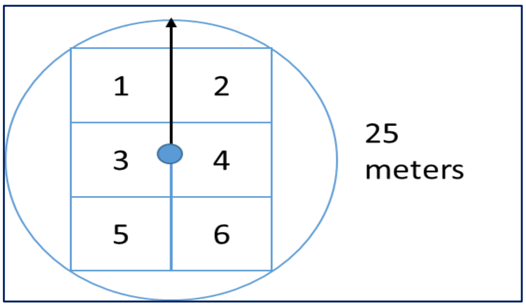


Figure 6.14 Single ZigBee Network Example

For a much larger area, such as that of an entire floor of a hospital, the placement of each coordinator and reader can become larger. An area of 100m by 100m can be covered through the strategic placement of 4 coordinators and 16 readers as shown in Figure 6.15. As the coordinators hold the strongest range, fewer are required. These devices received the data generated by the readers as the tags are tracked and monitored in real-time. Once an understanding of this scalability has been achieved, implementation for an entire hospital becomes a much less daunting task.

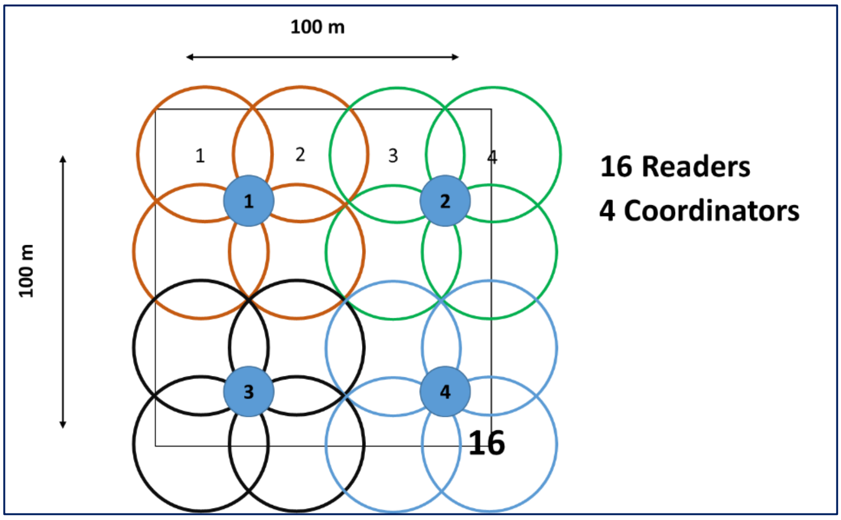


Figure 6.15 4-coordinator ZigBee network example

Within the hospital environment, a number of staff and a number of medical devices in use were fitted with a ZigBee tag, which transmits its unique ID at pre-set intervals. Signals from the ZigBee tags were picked up through the use of both mobile readers and the pre-determined network of fixed readers. As the healthcare providers and medical devices travelled around the hospital with their tags, the readers performed continuous searches for their data. With a readability range of 25 meters each reader records the date, time and location for each transmission from any tagged item. The data are uploaded immediately to the main database via the fixed network. The designed application allows authorised users to quickly search the database to see visually the current location of an item or to generate a historical report showing where it has been over a defined timeframe. This store of location information helps to deliver improved visibility of items, to optimise utilisation and to improve overall operational and financial performance.

6.8.3 Results of Proof of Concepts Experiments

The results from both proof of concepts experiments were significant and demonstrated the success of the proposed system. For the first experiment, a visualisation of the real location mapped against the tracked system location is shown in Figure 6.16. The nearly constant movement of the subject was tracked with precision, especially considering the straight lines shown for the tracked location used to approximate the real location. The largest deviations for the paths occurred when the subject made sweeping turns that the linear approximation is unable to perfectly follow. The results indicate strong adherence to the real location with applicability to the search for medical devices very reasonably reliable under these indoor conditions. The accuracy of the results proves that device location could be shown to a healthcare provider searching the database, providing information not only on the device's room but on their location within the room as well.

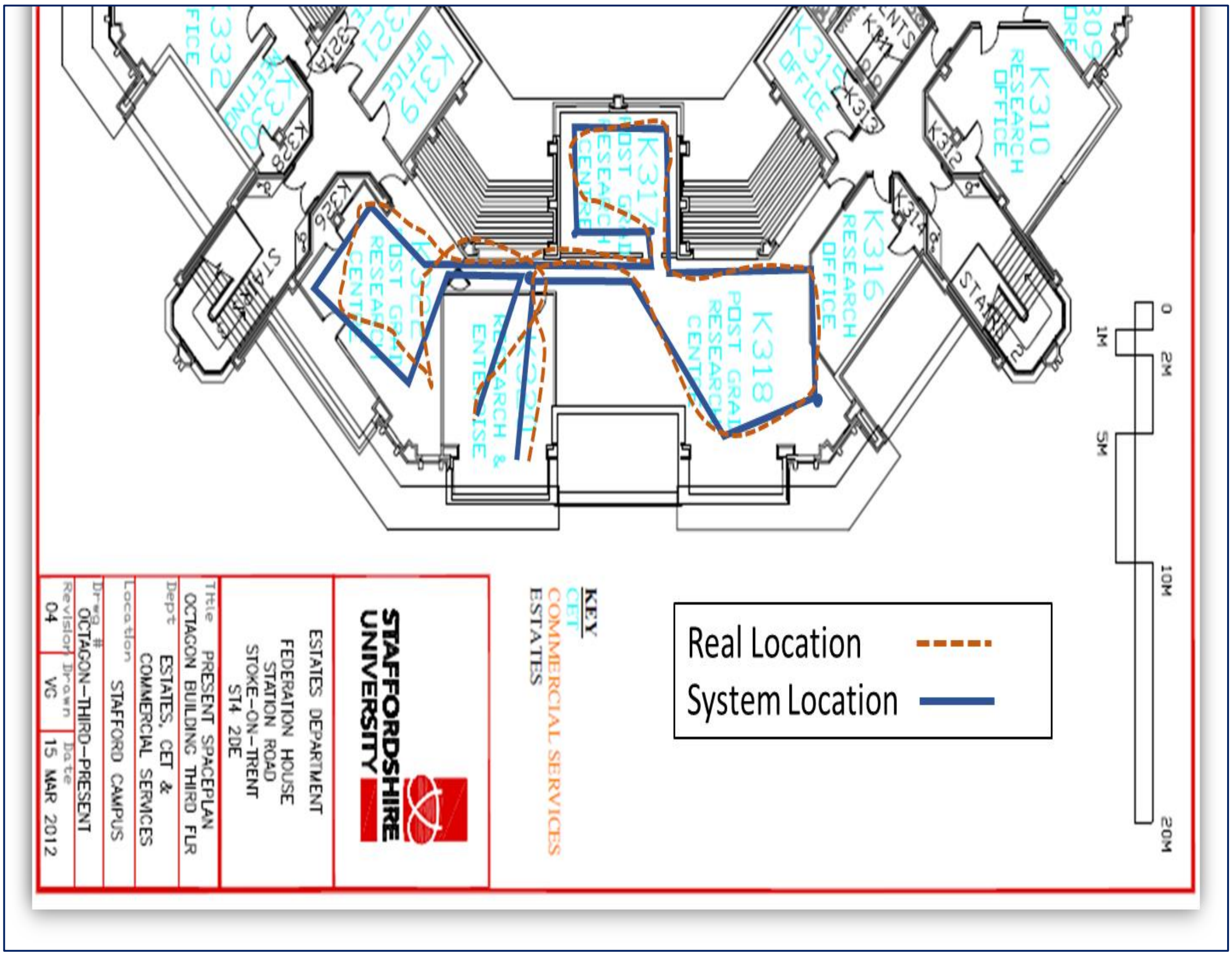


Figure 6.16 Results for the Laboratory Experiment

The second experiment also proved the success of the proposed e-health system. When asked to locate a member of staff using the traditional way, between 5 and 10 minutes were consumed for 5 members of staff. Figure 6.17 shows the drastic improvements when hospital staff were tagged using ZigBee technology and subsequently searched for. As shown in Figure 6.17, the improvements show the significant benefits of real-time tracking and monitoring technology. Tracked hospital staff were located in between 3 and 5 seconds, which simply represents the time required to press the button for requesting the staff's last known location. This system therefore resolves the deficiencies established by the questionnaire in the previous chapter.

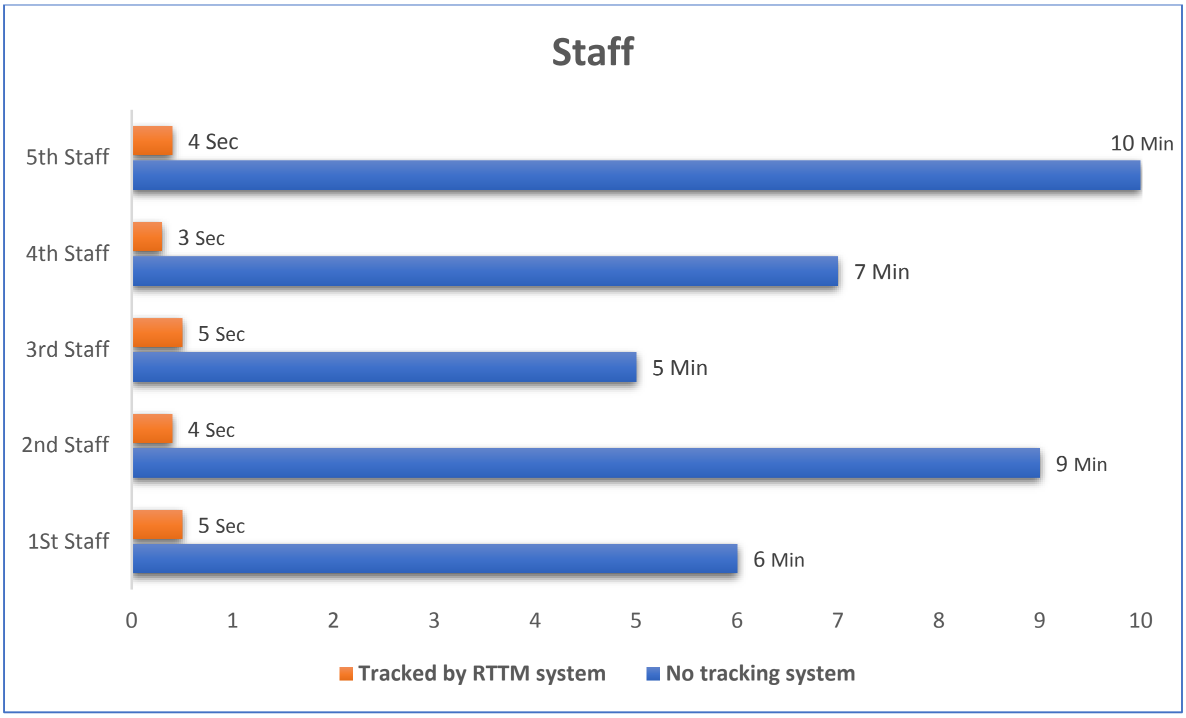


Figure 6.17 Results for the hospital experiment for the tracking and monitoring of staff

The tracking and locating of medical devices was the second point of interest for the hospital experimental trial. Figure 6.18 shows that for 5 medical devices, the traditional system required between 11 and 20 minutes of staff time in locating the device. This was similar to the results for staff tracking and locating. The e-health system allowed for the devices to be located in between 2 and 3 seconds. These improvements bring the ability to locate an item into the realm of modern technology, as these results represent the minimum time possible on the human level. The use of tracking system in conjunction with simulation scenarios as proposed in Chapter 7, would improve the patient experience in terms of waiting times in a hospitals system. It is important to note that the devices and software comprising this technology were not a financial burden for the research, and that application across an entire healthcare organisation such as a hospital should be financially viable.

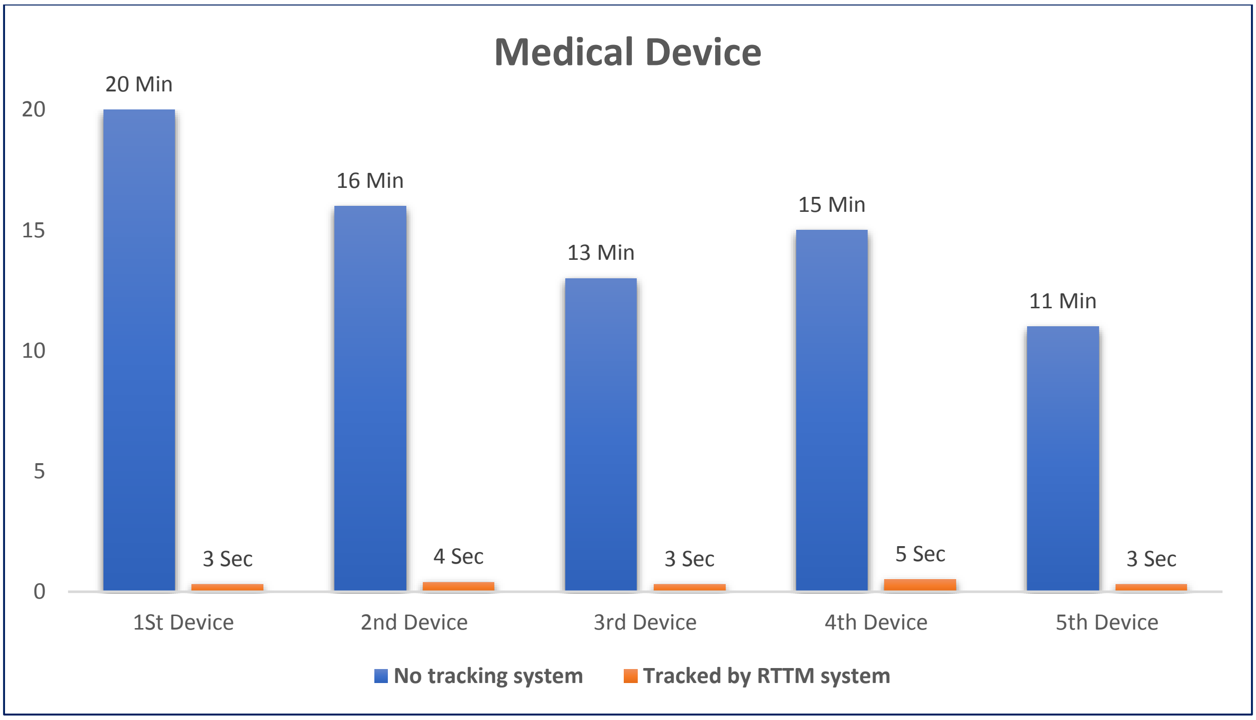


Figure 6.18 Results for the hospital experiment for the tracking and monitoring of medical devices

6.9 Conclusion

This chapter has overviewed most of workflow challenges that have arisen particularly in the Saudi Arabian healthcare, as well as improvements in workflow that have surfaced in the literature. Simulation was considered and used for this study, in order to apply it to workflow improvement and to test the proposed e-health system suggested by the holistic framework generated and refined by the literature, the CoP and the questionnaire. Furthermore, two experiments (Section 6.8) were performed to determine the power and accuracy of the proposed e-health system. The laboratory experiment assessed the precision of the e-health system in tracking a human subject around the indoor location. The second proof of concept experiment used a real hospital setting, real-time staff, and medical device movements, to assess the performance of the real time tacking and monitoring system. This experiment was also significant, as it reduced the time to locate a desired item from minutes to two to three seconds.

The designed and performed simulations covered the workflow system currently used in most KSA hospitals (Section 6.6.1), providing results to compare and contrast with the improvements simulated next. It was decided to exploit the designed simulation model to study the optimisation of the deployment of staff and medical devices (Sections 6.6.2 & 6.6.3). The results were enlightening and could be used directly in some KSA hospitals. The simulation of the hospital with e-health (Section 6.7) showed in a measurable way how important the advantages of e-health would be, and provided material for the cost-benefit analysis that would be required for its adoption.

The experience gained in the work covered in this chapter, suggested that combination of simulation and e-health system with visual tools, could provide relatively low cost and easy-to-use software tools for performing not only tracking and monitoring, but also simple provision of optimal solutions to common, every-day, staff and devices deployment problems arising in KSA hospitals.

The process of simulation used in this chapter required visualisation tools that have been advocated in the holistic framework, for use in considering a healthcare organisation's options and in selecting an appropriate system. Alongside visualisation is the concept of knowledge management, both of which are discussed in the following chapter for the purpose of improving the efficiency and performance of staff and assets and in improving patient-centric care.

Chapter 7 Knowledge Management Transformation by a Real-Time Tracking and Monitoring (RTTM) System

7.1 Introduction

This chapter has followed the development and refinement of a holistic framework for the use of Real-Time Tracking and Monitoring (RTTM) for a hospital healthcare system. Chapter 6 illustrated the technology system in action through two aspects, which are: firstly, workflow improvements, and secondly proof of concept trail experimentations, with results shown visually. This visualisation, discussed in this chapter, will be shown as vital to the continual improvement and knowledge transformation of a healthcare institution, regarding productivity, efficiency, staff performance, and patients' centric care and satisfaction rates.

This chapter begins with an overview of knowledge management, which encompasses the topic of data, information and knowledge visualisation. The SECI (Socialisation, Externalisation, Combination, and Internalisation) model of knowledge dimensions, which is derived from research in the knowledge management literature, is overviewed next, with its four elements outlined. These elements are socialisation, externalisation, combination and internalisation. This is followed by a discussion of explicit, implicit and tacit knowledge, and by the advocating of the transformation from tacit to explicit knowledge in the context of the Saudi healthcare system. This is the core of knowledge dynamics that is applied for healthcare improvements. The chapter then illustrates data visualisation, and integrates it with knowledge management for a developed system to be implemented in Saudi healthcare institutions. This is achieved through many outlets, including: the tracking and monitoring of staff, patients and medical assets; mobile Wayfinding and indoor navigation; infant tracking and monitoring; a hospital performance dashboard; and hospital staff training and learning tools.

7.2 Knowledge Management

There are several definitions of knowledge management (KM), but the focus is on enhancing organisational performance through the development and implementation of tools, processes, systems, and cultures for the improvement of the production, sharing and use of knowledge (Holt et al., 2007). KM is critical for decision making, and it is also a necessary vehicle for change in such complex work environments as hospitals. KM relates to organisational learning, business administration and information systems (Dubberly & Evenson, 2011), concepts that permeate an entire healthcare institution. Just as in change management, knowledge management requires decision makers to evaluate their organisation's readiness to implement any proposed changes. Similarly, as with change management, KM can be improperly assessed or implemented, causing resistance by members of staff and leading to failure to maintain the change (Frost, 2014). The concept of resistance to change is important: '*a critical question for organisations that are thinking of attempting to extract value implicit from KM is to what degree they are ready to have KM successfully adopted by people in the organisation*' (Shaw & Tuggle, 2003 in Holt et al., 2007). Without KM readiness, resistance is likely to increase, and the rate of failure to be high. KM follows a cyclical process and may best be represented through six steps as follows: (Easa & Fincham, 2012):

1. Creating knowledge.
2. Capturing knowledge.
3. Refining knowledge.
4. Storing/codifying knowledge.
5. Keeping knowledge updated.
6. Disseminating knowledge.

These steps are used as a guide for this research in the development of a unique approach to KM. KM is designed to utilises concepts from the operations management, and to supply chain management literature, with the aim of improving the customer's experience with the organisations, and helping the organisations to maintain a competitive advantage. This research preserves its focus on improving the patient's various experiences with healthcare institutions and, as has been demonstrated by surveys of physicians, competitive advantage is one of the objective for hospitals (Lai et al., 2014). Therefore, KM targets process improvements aimed at easing the work required for healthcare staff, while simultaneously improving the performance metrics tied to patient centric care, such as patient misidentification and waiting times.

KM is relevant in healthcare because the sector employs Knowledge Workers (KWs). Knowledge workers are people whose jobs require the handling or using information to provide knowledge. Another definition of KWs is: those people who use their brain more than they use their muscles for their tasks (Mládková, 2011). This is most apparent for managers and decision makers for the running and direction of a hospital, but it is also highly influential in the work of physicians, whose decisions on diagnoses and treatments are based on available data, and in the work of nursing staff, who require real-time information on patients' histories, locations and statuses, and on hospital schedules. The proper utilisation of knowledge by KWs prevents a hospital from breaking down on an hourly basis. Knowledge work also provides low work visibility, and so its results can be indirect, and its effects delayed. Knowledge for KWs is diffused within the minds of the organisation's staff, while knowledge for non-knowledge work is concentrated with the managers (Mládková, 2011). The workers are so relevant because knowledge is inherently created from humans' interaction with each other and with their environments (Bratiănu, 2016). Additionally, knowledge sharing occurs frequently via personal conversations, and this knowledge is typically informal (Davenport & Prusak, 2000 in Easa, 2012). The groups through which this informal knowledge is transferred are difficult to analyse, but this is a place for resistance or support for new systems to be formed.

Knowledge management is driven by various strategies that are derived from differing understandings of knowledge. From the perspective of knowledge as an *object*, KM aims to build information databases; from the perspective of knowledge as a *process*, KM aims to optimise the knowledge-intensive processes, such as the identification, creation and sharing of knowledge; from the perspective of knowledge as *capability*, KM focuses on the strategic advantage of knowledge to build on its core competencies and to create intellectual capital; from the perspective of knowledge as a condition of information *access*, KM looks at methods to identify, retrieve and gain access to information; and from the perspective of knowledge as a *state* of knowing and understanding, KM encourages individuals in their expansion of knowledge (Burkhard, 2005). What links all these diverging perspectives, is that Knowledge is dynamic as it links with flows and processes. Knowledge flow relates to how it moves throughout an entire organisation, while knowledge processes refer primarily to explicit knowledge, or to the transformation of tacit knowledge into explicit knowledge (Bratiănu, 2016; Burkhard, 2005).

Research has indicated that there are three types of knowledge: tacit, explicit and implicit (Karamitri et al., 2017; Dalkir, 2005; Nonaka, 1994; Kaiser et al., 2008; Nonaka et al., 2000; Lee, 2001). Tacit knowledge is '*highly personal and hard to formalise'*, which makes it difficult to communicate it with others. Tacit knowledge covers subjective insights and intuitions, and is grounded in individuals' actions and experiences. Explicit knowledge is much easier to define; it is the form of knowledge that can be expressed in language and transferred verbally or through written communication via any context. Some research indicates that the third type of knowledge, called implicit, is '*knowledge that can be expressed in verbal, symbolic or written form, but not yet expressed*' (Lee, 2001). Some studies, such as Dubois & Wilkerson, (2008), differentiate between tacit and implicit, and outline that tacit is: '*knowledge that cannot be written* down' and implicit as: '*that can be written down but has not been written down yet*', while others, however, do not differentiate between tacit and implicit and consider the types of knowledge only as tacit and explicit (Pathak, 2014; King, 2009). The transformation of knowledge between the forms of knowledge is covered later in this chapter, but the dynamic dimension of knowledge is important. One of the simplest forms of knowledge flow is knowledge sharing, which, as has been mentioned previously, is treated differently in the Arab world for a variety of reasons (Yeo & Gold, 2014) that will be explored in Section 7.5, on the transformation of knowledge from tacit to explicit in Saudi healthcare. The different culture of Saudi Arabia, as it affects knowledge sharing, is critical for an organisation to understand in order to successfully implement KM. The next section puts forward one of the most prominent models of KM, the SECI model.

7.3 SECI Model

The SECI model, which has been in existence since 1993 (Easa, 2012), has emerged from research in the knowledge management literature as it facilitates the transformation of knowledge from tacit to explicit knowledge. The creator of the SECI model, Ikujiro Nonaka, argued that there are four modes of knowledge transformation created '*when tacit and explicit knowledge interact'* (Dubberly & Evenson, 2011). This model follows an iterative process in the form of an outward spiral as shown in Figure 7.1. Each loop intensifies the knowledge for an entity that creates higher levels of knowledge. This process begins with individuals, moves to groups, then organisations and finally communities of organisations. The final entity is a broader form of the Communities of practice (CoPs), utilised consistently throughout this research, and here its expertise becomes visible. CoPs are communities of organisations that deliberately coordinate and collaborate to do something better through regular interaction (Agrifoglio, 2015; Wenger, 2015).

Figure 7.1 also provides the basic definitions of each of the four modes of knowledge conversion, which include socialisation, externalisation, combination and internalisation. These definitions, taken from Dubberly and Evenson (2011), are as follows:

1. *Socialisation*: Sharing and creating tacit knowledge through direct and shared experiences in daily social interaction.
2. *Externalisation*: Articulating tacit knowledge through dialogue and reflection, so that it can be shared by others to become a foundation for new knowledge.
3. *Combination*: Systemising and applying explicit knowledge and information from inside or outside the organisation for its combination, editing or processing, so that it can become more complex and systematic explicit knowledge, which is disseminated throughout the organisation.
4. *Internalisation*: Learning and acquiring new tacit knowledge through its conversion by individuals from explicit knowledge. Here, knowledge is used practically and forms the basis of new routines.

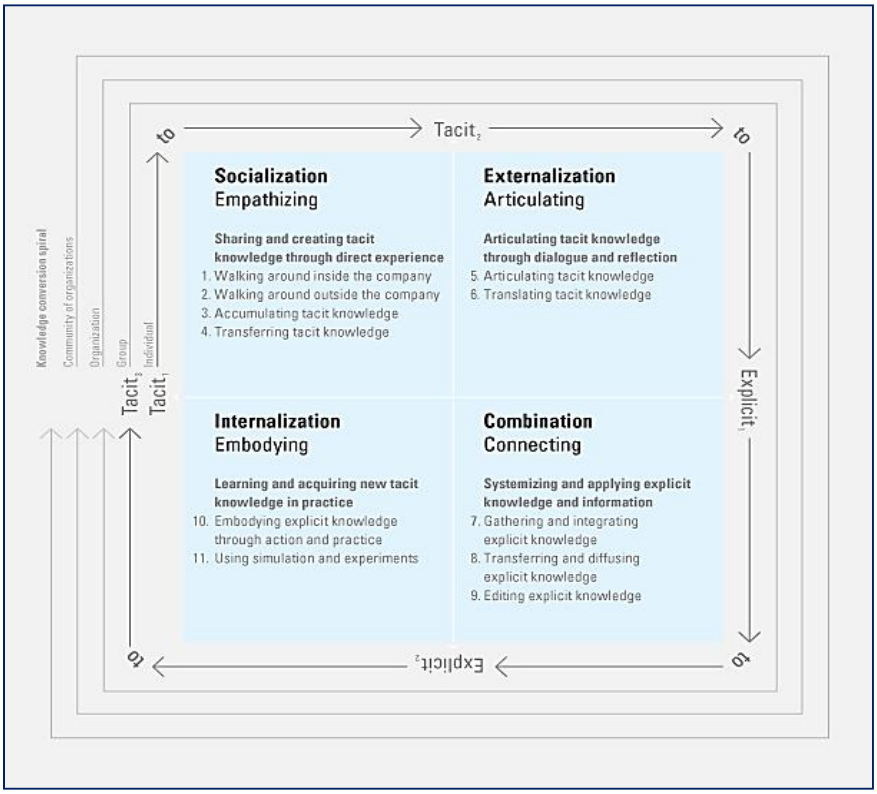


Figure 7.1 The SECI Model spiral of knowledge conversion (Dubberly et al., 2011)

A number of methods are also provided, which guide specific practices to be performed; these methods facilitate knowledge conversion between tacit and explicit knowledge, as shown in Figure 7.2. This diagram is a reminder that socialisation is the process of converting tacit into tacit knowledge, externalisation is the process of converting tacit into explicit knowledge, combination is the process of converting explicit to explicit knowledge, and internalisation is the process of converting explicit into tacit knowledge (Nonaka, 1994). Each of the four modes will be discussed thoroughly in the following sections.

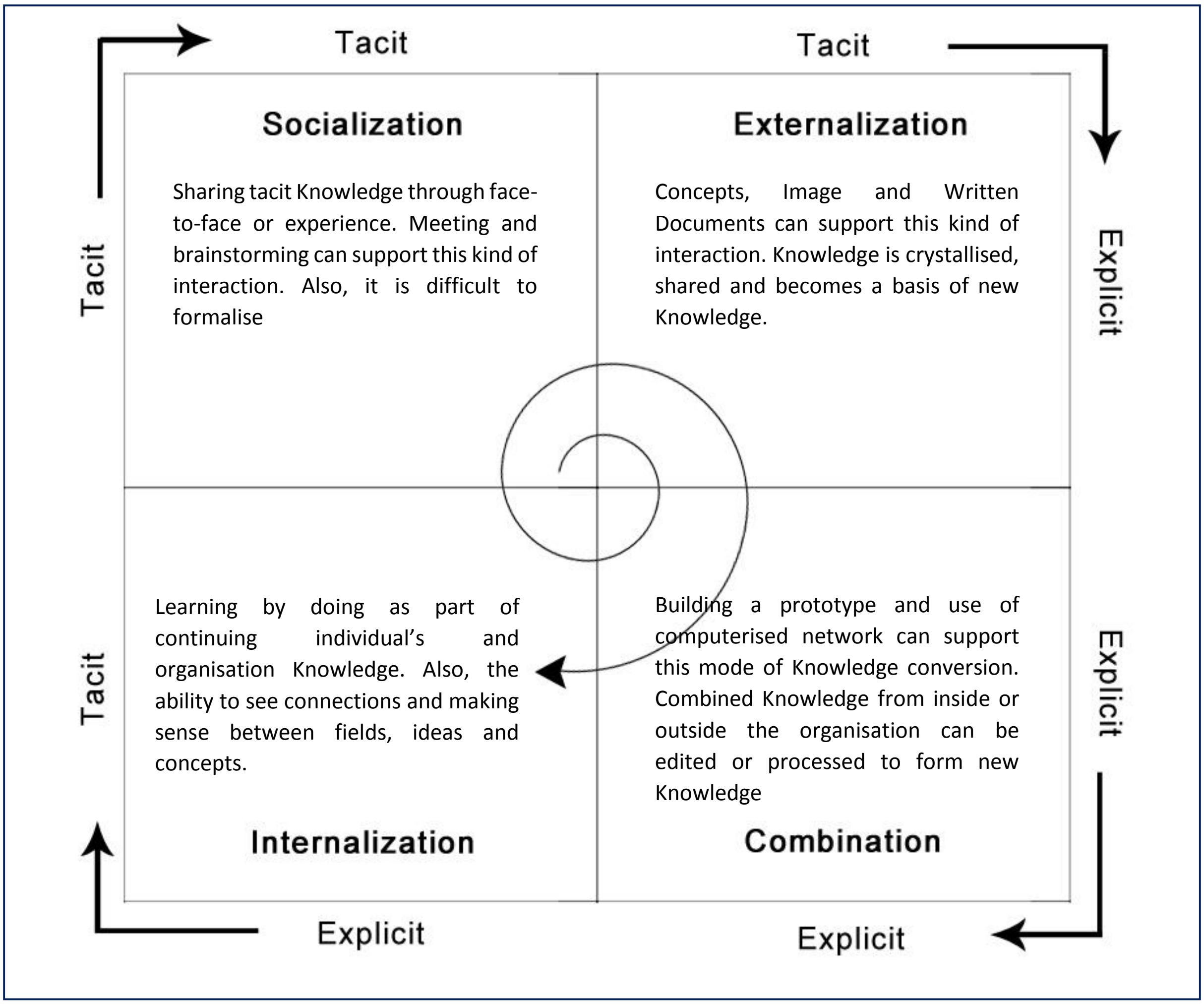


Figure 7.2 Nonaka's model of knowledge conversion modes (Nonaka, 1994). Modified by author.

7.3.1 Socialisation

Socialisation is the process through which an entity converts or transforms tacit knowledge to new tacit knowledge. This occurs through daily interactions between individuals and groups, as well as ongoing activities within an organisation (Easa, 2012). Tacit knowledge can be acquired by individuals without the use of language, as this mode of knowledge conversion utilises observation, imitation and practice (Nonaka, 1994). On-the-job training, such as through an apprenticeship, is also undertaken without the need for language, as this activity typically relies on experience. This ‘shared’ experience is critical for the transfer of information to be successful. Nonaka calls this ‘socialisation’ due to its highly interactive nature. It is also more informal than other knowledge conversion modes, as it frequently takes place in social settings outside the workplace. Beliefs and world views can be shared, and mental models and mutual trust can be created. Additionally, organisations can utilise the tacit knowledge embedded in their institutional clients or suppliers through simple interaction (Nonaka et al., 2000).

Socialisation is applicable to the healthcare sector at every level, from interactions between nurse and patient to interactions between management and physician. The institutional clients mentioned above can easily be translated into the hospital’s patients, and suppliers remain relevant, as all healthcare organisations require many medical devices, some of which are ordered in bulk and designated for a single use, and some that are expensive pieces of equipment that are expected to last for years. The tacit knowledge gained from suppliers can teach individuals within the healthcare organisation in informal ways that can help their strategies toward improving patients’ care. Returning to the patients as translated from customers or institutional clients, nurses interact with them, particularly inpatients, multiple times daily. These informal interactions can allow the nursing staff to extract tacit knowledge on processes the patients see as inadequate, on perceptions of a new technology system, and so on. This habit is as useful to the organisation as its staff members allow it to become.

7.3.2 Externalisation

Externalisation is the process through which tacit knowledge is converted to explicit knowledge, which occurs once the organisation formalises its set of internal rules for processes and functions, usually through written documents. The written form of explicit knowledge makes it ‘crystallised’ and allows it to be shared upon demand, and is therefore the basis of new knowledge (Nonaka et al., 2000). This crystallisation is enabled through the exchange and combination of knowledge between individuals, possibly through meetings or phone calls. This mode of knowledge conversion also includes reconfiguration ‘*of existing information through the sorting, adding, re-categorising and re-contextualising of explicit knowledge’* (Nonaka, 1994). For organisations, the creation of concepts when developing new products exemplifies externalisation (Nonaka et al., 2000). Within a hospital, an example is the articulation of tacit knowledge aggregated, possibly by all nursing staff, over the course of time.

Engagement and learning tools, such as meetings and workshops, have been introduced in previous chapters of this research, and these kinds of practices, when dialogue is documented, represent the process of externalisation. Training staff is for many reasons such an important step in the holistic framework introduced in Chapter 4, and the processes of socialisation and externalisation are leading reasons. The crystallisation of knowledge through training programmes and workshops makes for simple externalisation. Reporting the outcomes of these events is one of the most common forms of documenting dialogue; this promotes the contradictions of tacit knowledge between individuals to become clear and to be synthesised (Easa, 2012). Workshops and ongoing training by IT experts within the healthcare organisation, for the implementation of a new technology system, are therefore highly advocated by the holistic framework for this research. Training processes by IT staff, as they progress (possibly for the first time) with the hospital's nursing staff, should be visualised, so that common technical issues, knowledge gaps of new users, and best practices for future training sessions can be visualised.

7.3.3 Combination

Combination is the process through which explicit knowledge is converted into more complex and systematic sets of explicit knowledge. This occurs through the collection, combination and editing or processing of explicit knowledge, to form new knowledge, which is then disseminated throughout the organisation. This mode of knowledge conversion is achieved best through the creative use of intra-network communications, such as through interactive and visualised systems (Nonaka et al., 2000).

The implementation of a new health information technology system provides the foundation for combination to be quickly activated and to advance a variety of processes throughout the healthcare organisation. Many details regarding the use of an integrated RFID/ZigBee system, and of improvements made through the addition of this technology, are discussed in the Sections 7.9. A summary of the benefits includes addressing the problems discussed in Chapter 2 (i.e., patient misidentification, waiting times, etc.), the use of a hospital performance dashboard and the development of hospital staff training and learning tools. The characteristics of the technology introduced through the RTTM system allow it to be easily integrated with computer systems, and for the process of combination to be taken advantage of, possibly for the first time with real benefits for many hospitals in Saudi Arabia.

7.3.4 Internalisation

Internalisation is the process through which explicit knowledge is embodied and converted into tacit knowledge. This process involves the creation of new tacit knowledge through the use and sharing of existing explicit knowledge. Internalisation is similar to '*learning by doing*' (Nonaka et al., 2000) and bears the most similarity to traditional learning. Additionally, both combination and internalisation capture the complementary nature of tacit and explicit knowledge, and how both can expand over time through mutual interaction (Nonaka, 1994). Ultimately, internalisation is the opposite of externalisation and is realised through a social context (Bratiănu, 2016). It also occurs through individuals reading the documents provided after the most recent phase of combination has been completed. This process demands that the individuals internalise the explicit knowledge as well, in order to enrich their personal tacit knowledge (Nonaka et al., 2000). The tacit knowledge at the end is then available for utilisation in the next spiral of the SECI model, as it builds on the previous one.

In healthcare, internalisation can be achieved through a variety of methods. Cross-functional teams engaged with management allow the managers to understand shared values and ideas, and to subsequently share this knowledge with management to develop new visions and values. The activities of simulation and experimentation, which have been employed in this research from Chapter 6, and which demonstrated the internalisation of the holistic framework set before it, can also be utilised in Saudi hospitals, where experiments and analysis are done to advance continually the research and improve hospital processes. Additionally, with the use of the RTTM system, a healthcare organisation's help to support changes in workflow which can be much better approximated. Combined with the use of internalisation of visual displays, hospital staff will be able to understand better processes and cross-sectional layouts, and form foundations for future improvements via socialisation.

7.4 Explicit Knowledge

As stated in the introduction of this chapter, explicit knowledge is the form of knowledge that can be expressed in language and transferred verbally or through written communication via any context (Yeo & Gold, 2014). It is more visual and more directly understandable than tacit knowledge, as it can easily be communicated and transferred, and can come in many forms, including manuals, blueprints or maps, procedures, policies, schedules, and so on (Schoenherr et al., 2014). Nonaka and Takeuchi (1995) provided the '*iceberg'* metaphor in their theory of knowledge dynamics, asserting that explicit knowledge is the visible part of the iceberg and comprises a small portion of the entire knowledge, and that tacit knowledge is underwater and comprises most of the knowledge.

Although, concepts surrounding knowledge management and knowledge dynamics are rooted in supply chain management (specifically supply chain knowledge management capability, SCKMC), these ideas are just as relevant in healthcare. SCKMC exists on a continuum with a range from tacit to explicit knowledge (Schoenherr et al., 2014). The SCKMC has also contributed to the understanding of the capacity of knowledge to develop in the supply chain (Craighead et al., 2009). This is applicable to healthcare as well, through the relation provided in the section on internalisation through the SECI model, when a healthcare organisation learns from the competitive advantage required from its suppliers.

7.5 Transition from Tacit to Explicit Knowledge in Saudi Healthcare

In the context of healthcare, knowledge is *'more significant than in any other industry'* (Zaher, 2012). A study by Yeo and Gold (2014) claims that Saudi Arabia is a closed country in which interaction between males and females is not completely free, that it is a male-dominant society and is composed of a complex collection of nationalities that are affected by nationalist strategies. As far as KM is concerned, Saudi Arabia is also disadvantaged by language barriers; organisational barriers such as poor management support, poor organisational structures, lack of leadership, and insufficient planning. Additionally, there are human barriers such as cultural differences, employees' resistance to change, time requirements and staff retirement. Then, there are also technical barriers such as inadequate infrastructure, poor IT design and planning, poor networking, lack of maintenance and training; political barriers; and financial barriers such as the global economy, poor financial investment for the organisation and insufficient IT investment (Yeo & Gold, 2014; Zaher, 2012). The most important challenges in implementing KM as designated by Migdadi (2009) are the measuring of financial outcomes of KM efforts and the organisation's ability to maintain an updated IT infrastructure. Given the significance of the financial burden of an integrated RTTM system as perceived by hospital management, measuring financial improvements as caused by the new system, is vital to its being utilised to its intended capacity. This has further implications that will be discussed in the Section 7.9. Additionally, an up-to-date IT infrastructure is what the holistic framework developed by this research aims to provide; though its maintenance, even as part of the framework, is shown here to be vital.

The need for the development of knowledge sharing has never been greater as the country joins the Middle East in its plans of internationalisation (Yeo & Gold, 2014). Saudi Arabia's current strategy, however, is aligned with positive change, as it has recently introduced a development plan that shifts the country to a knowledge-based economy (Zaher, 2012). Integrating IT infrastructure into the healthcare sector will facilitate this shift, and it can lead the cultural evolution into more openness. The RTTM system described in this research promotes knowledge sharing through many facets, such as visualising the organisation's layout and progress over time, providing features linked with mobile applications for healthcare practitioners' Smartphones, and increasing patients' knowledge of their own medical history and of the reliability of the healthcare system. Knowledge sharing is the pivot on which knowledge management moves, and is the foundation of every mode of knowledge conversion within the SECI model (Battistutti & Bork, 2017; Nonaka, 1994). Although many barriers exist and are being addressed in the country's ongoing development plan, knowledge management is most likely to be successful in Saudi healthcare organisations only if knowledge sharing is promoted (Asrar-ul-Haq & Anwar, 2016). Tacit knowledge *'lives in the minds of individuals'* and represents underutilised potential when an organisation is available. Therefore, the shift from tacit to explicit knowledge for entire healthcare organisations in Saudi Arabia requires socialisation as its first step; and from this step the new tacit knowledge can be 'crystallised' into explicit knowledge from which future knowledge can build (Battistutti & Bork, 2017; Nonaka et al., 2000).

7.6 Visualisation in the Healthcare System

Aspects of knowledge management are devoted to knowledge visualisation, which examines visual representations to enhance the management of knowledge at all levels, including personal, interpersonal, group, organisational, inter-organisational and societal. These practices utilise graphics that assist in the production, assessment, measurement, conveyance or application of knowledge to create insights (Eppler & Burkhard, 2007). Examples extend to heuristic sketches, conceptual diagrams, and knowledge maps. This research makes use of the ability of an updating real-time tracking and monitoring technology system to automatically visualise knowledge in hospitals to support decision making.

In hospital systems, even with the complexities permeating every process and department, standardised methods are in place for automatically analysing the automatically produced data. The combination phase of the SECI model is when this collection of data is utilised to its fullest potential for the organisation. As applied to healthcare, the visualisation provided from knowledge created in the real-time tracking and monitoring system, must be insightful, address the problems identified in Chapter 2, focus on improving the patients' experience, and abide by a policy of constant development and improvement. Knowledge visualisation should ideally simplify performance metrics and trends, so that the analytics are not adding to the organisation's complexity. Table 7.1 shows how cost reduction, service improvement and revenue increasement, as derived from RTTM system implementation, lead to larger benefits. The RTTM system aims to supply these benefits with knowledge transformation, using visualisation. For example, knowledge visualisation can be used to reduce the required labour force needed for this work to complete part of the workflow process by visualising how long the process takes and either reassigning or relocating staff appropriately. This visualisation can be time-based or compared with other ongoing processes within the facility, to determine whether staff can be reallocated to other departments to assist them. Another indirect benefit of this system is its ability to record data for future use if legal complaints, should they arise; this can save a hospital large sums of money if legal cases can be avoided altogether through the evidence provided with the stored location data. The remaining benefits listed can be approached through appropriate graphics that capture the associated performance metric (i.e., inventory levels and locations for a specific asset over time).

Table 7.1 Key drivers for benefits from implementation of RTTM system (Ma et al., 2011). Modified by auhor

Key Drivers for Benefits	
Cost Reduction	Reduce required healthcare professionals / time
	Reduce the medical supply shortage rate, emergent order, expiration waste and inventory level
	Reduce the lost assets/rental rate of equipment, locate the missing assets
	Reduce paper-based documentation
Services Improvements	Increase capability of medical error-proof and prevention
	Reduce the patients' re-visit rate
	Increase working efficiency
	Increase patient effective treatment time
Revenue Increasement	Increase the number of patients served
	Increase the capability to serve referred patient
	Speed up the revenue capture rate
	Increase the utilisation rate of equipment

7.7 Principles of Designing Visualised Systems

The process of selecting appropriate media for use in visualised systems is of particular importance and is therefore considered in this section. The design of a visualised system must take into account the advantages and disadvantages of using various media, as well as be clear about the power and possible interfering effects of combinations of media. These principles are explored with discussion of individual mediums.

Some of the most commonly implemented media used in visualised systems include: (1) text input and output of text, (2) visual media, (3) icons, (4) maps, (5) N-dimensional models, (6) lists and tables, (7) graphs and charts, (8) network charts, (9) animation, (10) video, (11) gesture, and (12) sound input and output (Uden & Campion, 2000). These media types are beneficial for an organisation as they provide many options from which to choose, based on its organisational structure and culture, and on other relevant factors identified by the decision makers. The twelve categories of media listed above have been analysed in the literature with many factors in mind, including (1) whether it is an input or output medium, (2) typical medium usage, (3) how the medium is constructed, (4) operations that can manipulate the medium, (5) information that the medium can represent, (6) medium representation length, (7) positive aspects, (8) negative aspects, (9) degree of direct or indirect interpretation, (10) how the medium is attended or sensed by the user, (11) the kinds of attention operators available for the medium, (12) ability of the medium to set mood or emotion, (13) operational requirements, (14) hardware requirements, (15) other media that are integrable with the medium, (16) device compatibility, and (17) existing guidelines for the medium, based on research (Uden & Campion, 2000). Although not all of these factors will be relevant when an organisation analyses implementation of a medium, and some are more obviously important than others, these factors are very useful in approaching a strategy to design a visualised system. The media types are discussed as follows in the context of healthcare implementation.

Text remains the most common medium for both input and output, even with the use of technology (Shih & Alessi, 1996). It conveys as much details as is required, and is readily accessible to all literate people. In the use of text for a visualised system in healthcare, text must be clear and provide all details. A visualised system utilising text to convey information can do so on mobile and computer screens, so that it is accessible in any location, and brief but comprehensive. Visual media include pictures, drawings, sketches and diagrams, though other media are also ‘visual’ but in less photographic form. As the literature identifies visualisation as ‘the strongest human sense’, it must be utilised whenever allowable (Zhang et al., 2013). The argument is that the human brain can assimilate visuals information better than verbal equivalents, likely because it can focus on an image as a whole, whereas audio must be taken in single units (Bai et al., 2012). Better assimilation results in improved memory of the visual, which results in many benefits over time. Booher (1975) and Posner (1976) argue that improved visual media provides a strong enticement by gaining attention, direct communication, enrichment for emphasis of perspective, excitement, expression, explanation of complex relationships, and telling or supporting narratives. Pictorial representation of information is more economic and precise than verbally expressed information. Photographs provide direct representations of scenes, so that the viewer needs not rely on imagination, where inaccuracies may arise (Horne, 1994). In a visualised system in healthcare, visual media is of obvious benefit; one example is the use of pictures in learning processes, and another is the ability of one member of staff to quickly draw an illustration or sketch to convey information to another person. Knowledge can be visualised by this subset of media, using diagrams that are created by analysis of tracking and monitoring components, such as percentage of time a room is being used by nurses, doctors or patients. Visualising room usage can lead to analysis of its capacity in diagram form, and is therefore highly beneficial in healthcare.

Icons, which are well-recognised 'small visual symbols', are used in computing as a replacement for text (Rabaud & Belongie, 2005). These symbols represent the objects and are therefore simply for people to remember, as they fit the qualification of small images as described previously and can be assimilated into the memory quickly. Icons can be representational (directly relating to real-world objects), abstract (harder for people to relate, and usually concerning the object's function), arbitrary (having no visible link with their object), index (indicating a caused effect) and exemplar (representing a typical class or set) (Gatsou et al., 2012). Representational icons are therefore the fastest to learn and remember, and appear most frequently in standardised locations such as hospitals. Icons are used in healthcare to guide individuals to the proper location, or in storing an object where it belongs. Some universally recognised healthcare icons include the caduceus, the ambulance, hospital symbols, radioactive and poison warnings, and the heart. Consequently, identifying medical asset location using icons is relevant to a hospital setting. Visualised systems can easily develop a system for representing people by role and medical equipment by designated icons, so that a map of their real-time locations makes for improving knowledge management. The benefit of using computerised maps, as a medium is also relevant, as it pertains to the ability of users of the visualised systems to identify relative locations of people and objects based on a visualisation of their respective icons. Maps integrated with mobile devices additionally allow for navigation, as is discussed in the Section 7.10.2 on mobile wayfinding and indoor navigation.

Lists and tables, which can be represented in various forms, such as numbered lists or columns of data, are simplistic and allows for simple comparison of data. In a visualised healthcare system, the most common usage might be tables showing patient appointments that include columns for various times in the patient's process. A real-time tracking and monitoring system could automatically record these times whenever the patient's tag is located within a pre-specified area.

Graphs and charts represent and illumine numerical data extremely well, as comparisons, trends and other statistical measures can be visualised with these media. Trends of physicians' patient load over time, or of room usage over time, can provide helpful insights in healthcare. Pie charts can show a cross-sectional overview of patient profiles, and demographics as well.

These are also relatively simple to be automatically created by computer programs that analyse real-time data, so they are very useful in a visualised system in healthcare.

Network charts show visual interdependencies between components, through the use of graphics constructs like arrows and icons. These are essentially diagrams that can help visualise complex relationships, structures, sequences and processes, as shown in Table 7.2. These charts can be useful tools in visualising healthcare processes, such as the patient's process, and dividing it into various stages with branches incorporated.

Table 7.2 Network chart showing a work analysis of patient Hospitalisation. Source: (Rasmussen et al. 1991).

Network Charts	
1. Input / Output Media	Output media
2. Example of usage	A visual representation of boxes and relationship links, types; organisational chart, data model, decision tree, pert chart, flow chart, conceptual data model. Good for analysis, showing (interdependence, complex structures, sequence, decomposition and flow in abstract domains)
3. How constructed	2D lines, containment, lines, boxes, arrows, icons, distribution of components laid out on the display, symbolically described components, boxes indicating components, box shapes (or other iconic types), connections between components, connection types, symbolic labels on connections, basic metaphors, colour, texture etc.
4. Manipulation Operations available	Arrows, labels, language captions, title, font operations, symbols, icons, highlighters, colour, black and white, shape, line, metaphor, spatial arrangement, alignment, 1D, 2D, 3D
5. Compatible information Channels	Spatial
6. Message representation length	Prefer for relational messages
7. Positive aspects	Good for showing relationships
8. Negative aspects	Can be difficult for users to decode the chart
9. How interpreted	Direct
10. How attended/sensed	Passive, viewed by the eyes
11. Available attention operators	arrows, labels, language captions, title, font operations, zoom, symbols, icons, highlighters, flashing, simple animation, colour, unusual colours, space, alignment, scale, 1D, 2D, 3D
12. Can emotion be shown	N/A
13. Media Operational Requirements	Screen
14. Hardware Requirements	Computer, portable and mobile screens
15. Possible combinations	Animation, artificial sounds & noises, charts, diagrams, realistic drawings, gesture, graphs, icons, lists, n-models, natural sounds, maps, music, photo images, sketches, speech input, speech output, tables, text input, text output, and video
16. Device compatibility	Keyboard, mouse, track-ball, touch-screen, light pen, pen input, monitor

Animation, which represents dynamic concepts well (Campion, 1994; Rieber, 1990), may be less relevant in healthcare, as it is cited more for use in engineering processes. Video ‘clips’, though it similarly shows motion, may be more useful in healthcare in a learning and training aspect for hospital staff. Interactive videos allow users to replay, pause and skip sections of their training, based on their individual needs, so the use of this medium should be utilised in a visualised system as it concerns training procedures.

Gestures can be used by displaying them on the screen. This medium is used infrequently, as it requires virtual reality technology that is yet developing and may not be useful in healthcare until a later date.

Lastly, sound input and output are the most commonly used communication channel by human beings. Benefits include mental stimulation, gaining of attention, and generation of emotions. Ineffective usage can lead to annoyance, however, such as a loud television disrupting the expected quiet of a waiting room. Sound as a medium can be used in visualised systems as speech synthesis and recognition, which are of great benefit to deaf users who require speech to be visualised. In critical situations, a visualised system in healthcare provides methods for warning or emergency sounds that notify individual users, groups or an entire organisation of an event.

The many forms of media must be considered with respect to their strengths and weaknesses in the healthcare setting, and in how they can be best utilised to improve the visualisation of knowledge. The next section discusses this application to healthcare.

7.8 Knowledge Transformation using Visualisation for Healthcare Improvement in Saudi Healthcare

Eppler & Burkhard (2013) stated that knowledge visualisation requires determining number of elements as follow:

1. Type of knowledge that should be visualised
2. Reason for visualisation
3. Intended target audience
4. Context of visualisation
5. Method of representation

The content requiring visualisation in Saudi healthcare is firstly the locations and statuses of patients, hospital staff, and medical assets. Visualisation throughout a multi-level hospital, combined with analytical tools, allows to determine concentrations of individuals, general waiting times, and other important Key Performance Indicators (KPIs that can improve workflows, performance and efficiency. It is also ideal for patients to be able to visualise the often-expansive hospital setting, so that time is not wasted, and appointments are not frequently missed. Additionally, trends must be visualised in various functions, such as physician's patient load over time, asset utilisation and location over time, and patient satisfaction, as well as other ones.

The reasons for visualisation are: constant process improvement, asset utilisation, better patient centric care and flow, smoother workflows, more transparent procedures and knowledge, more open communication between staff and patients, and greater public trust and sentiment toward the healthcare sector, though other reasons exist and have been mentioned throughout this research. The intended target audience encompasses all stakeholders of the healthcare organisation, or everyone who encounters the facility. This includes staff, patients, families and visitors of patients, and CoPs. The context of visualisation is for everyday situations, including workshops and training for staff, virtual environments such as web-based and mobile applications, and for interactions between hospital personnel and patients. Lastly, the method of representation is readily available graphics for easily spotted trends and other insights, as well as communicative methods that give patients more access and connectedness to the organisation. Conceptual diagrams, knowledge maps, and interactive visualisations are all likely to be most useful in representing the knowledge to the stakeholders of the facility. The RTTM system presented in the following sections provides solutions that meet the needs outlined, with several real visualisations included for a clearer understanding of the specific insights produced from the management of this knowledge.

7.9 Rule-Based System for Real-Time Tracking and Monitoring (RTTM)

A rule-based system (RBS), commonly used in the creation of a *'Knowledge Based System (KBS)'*, uses rules to convert advanced knowledge into usable form for an organisation's production or procedures. The RBS requires sets of conditions and facts, as well as an entity to understand the current situation and determine solutions (Olajide et al., 2014). The RTTM system in this research used a KBS in its development, with the intention of constructing a decision support system (DSS). This helps proactive decisions to be made by processing and analysing vast quantities of data for knowledge visualisation. The KBS assists in the transfer of knowledge for Smart solutions and decision making (Tripathi, 2011). Rule-based reasoning substantially supports KBS (Liao, 2003) by collecting data from various locations (Bichindaritz et al., 1998; Syed-abdullah et al., 2015), which are converted to knowledge to be analysed by RTTM for proactive solutions to be made in hospitals. This research has looked at real hospital situations for the purpose of developing a real-time tracking and monitoring technology. As well as workflow improvements that provided solutions to the situations observed, Chapter 6 included two proof of concept experiments that produced data for use in the design of a rule-based system for the developed RTTM system considered in the following section.

7.10 The Developed RTTM System by Using Knowledge Management and Visualisation Concepts

The concepts of knowledge management and visualisation have been thoroughly discussed and are now ready for use in transforming healthcare organisations into Smart hospitals with RTTM system. These concepts could be applied to hospital staff, patients, medical equipment, mobile devices, maternity units, and could help in producing a hospital performance dashboard and hospital staff training and learning tools. All aspects are discussed, with sample graphics provided to illustrate the real visuals intended for final use.

7.10.1 Patient Tracking and Monitoring

The problems previously identified within Saudi healthcare, such as waiting time, patient flow and patient satisfaction, can be handled by effective use of a RTTM system. This begins with an effective registration process, which is improved through the following strategy:

1. Reducing the average amount of time required to register patients
2. Using the tracking system to identify which resources are most efficient at various situations.

3. Eliminating manual work, such as calls to other departments, by using the RTTM system to manage the transfer of patients, staff and medical assets between different services.

In Figure 7.3, a list of patients is made visible to the healthcare providers (Physicians, Nurses) at the clinic, with multiple graphics shown side-by-side. The graphic in the upper left focuses on the physician and the nurse as they attend to a patient. This is a time-based visualisation that shows the activities for one patient at a time, with the next patient in view, so that the nurses can prepare properly and manage their time. The table illustrated within this graphic provides visualised information for the visit duration, with the physician's averages compared with the standard norm based on the hospital policies. Simple summaries like this give instant analysis of how well a team is approaching the patient's process, and indicate areas in which improvements can be made. The bottom right chart visualises the physician's status, and the proportion of time spent by this physician with patients, alone or outside during the clinic time. It shows also the status of the clinic room, whether occupied, unoccupied or ready for clean-up. Those pie charts can inform the healthcare staff of deficiencies in the clinic, healthcare team, and facility processes, showing if patients' flow could be improved through better room utilisation. The table at the bottom of Figure 7.3 gives the healthcare team an overview of several patients at a glance, with each activity marked by a time that is automatically recorded by the tags attached to patients. The column on the right, 'duration' is automatically calculated and identifies deficiencies whenever the duration is higher than the standard. Consistent delays would be readily visible by this type of visualisation, and the re-locating of certain staff would become intuitive through this system.

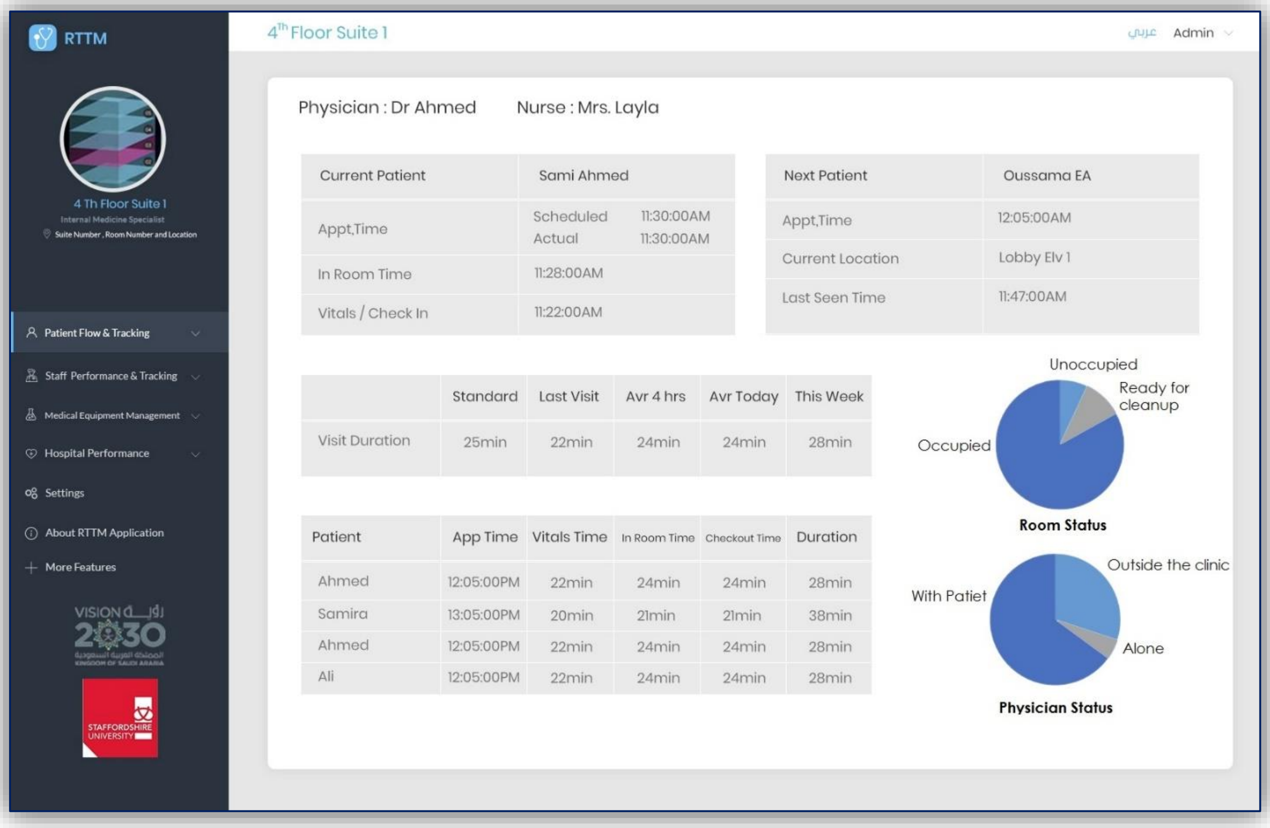


Figure 7.3 Patient Flow Tracking

Additionally, this process will subsequently address the problem of patient misidentification by providing tags that are attached to patients upon registration, so that later identification becomes as simple as checking the attached tag. Also, long patient waiting times can be reduced by identifying bottlenecks throughout the processing of patients, such as registration, waiting to be seen by the doctor, and queue for prescriptions at the pharmacy. With the RTTM system in place, an organisation is able to define its own 'activities, and track the time elapsed for each activity contributing to the patients' flow. Precise tags, such as with RFID and ZigBee, allow for locations to be accurate within a room, such as in Figure 7.4.

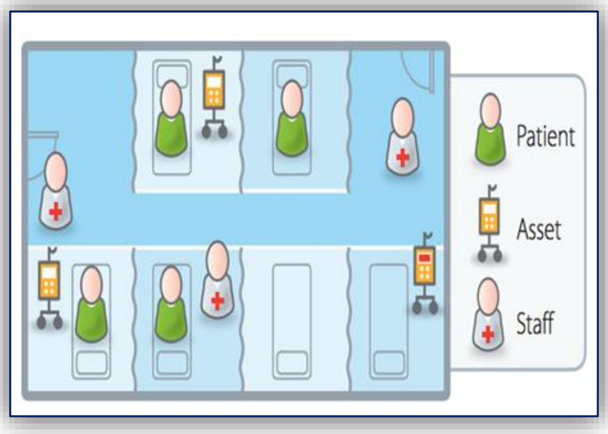


Figure 7.4 Within-room tracking and locating system with key

Figure 7.4 also provides the key for patients, assets and staff as shown in Figure 7.5. With this kind of visualisation, large groups of registered patients would be identified quickly, and nursing staff would be directed accordingly to manage the patient flow.

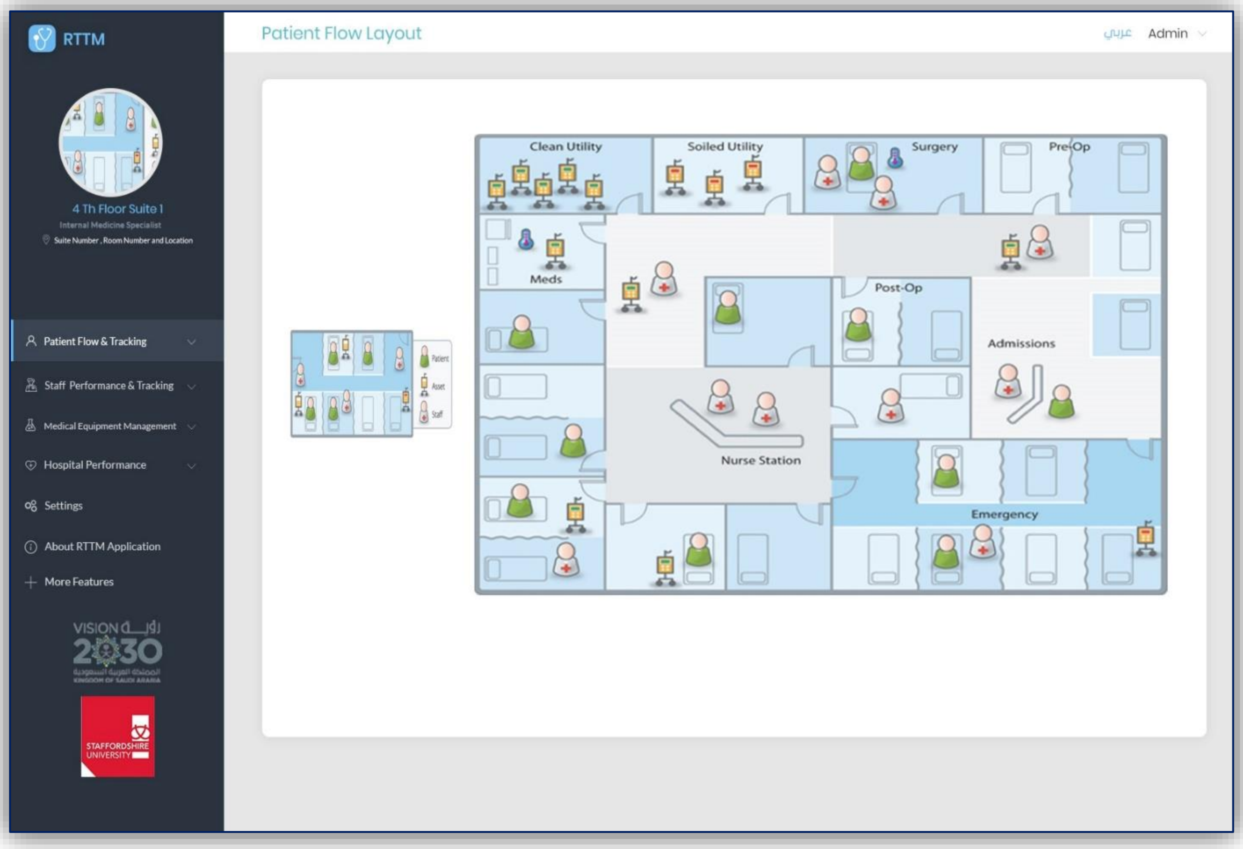


Figure 7.5 Patient flow layout

The final patient-oriented problem discussed in Chapter 2 is that of patients' satisfaction. Although it is logical that long waiting times are associated with dissatisfied patients, the RTTM system can assist in increasing patient satisfaction. A healthcare organisation must communicate with patients (externalisation) through features enabled by the tracking and monitoring system. One of these features is provided by hospital policy-compliant interactive messages, sent to patients, their visitors and family members, as shown in Figure 7.6. The primary benefit of these interactive notifications is the ability to remind patients of their appointment times, so that delays are not incurred in the registration process. Additionally, for post-operation surgeries, patients would be notified to remind them about the appointment as well as to where to go and when. Notifications can also provide status updates to family members, even while they are outside the building. The added benefit of these notification messages is their contribution to the improvement of patient satisfaction. Open communication facilitates accountability of the healthcare organisation, and trust by the patients and their families. This messaging system is linked to the RTTM system and runs through automatic triggers, based on a set of pre-defined criteria as established by the organisation, and the messages are stored securely for later retrieval.

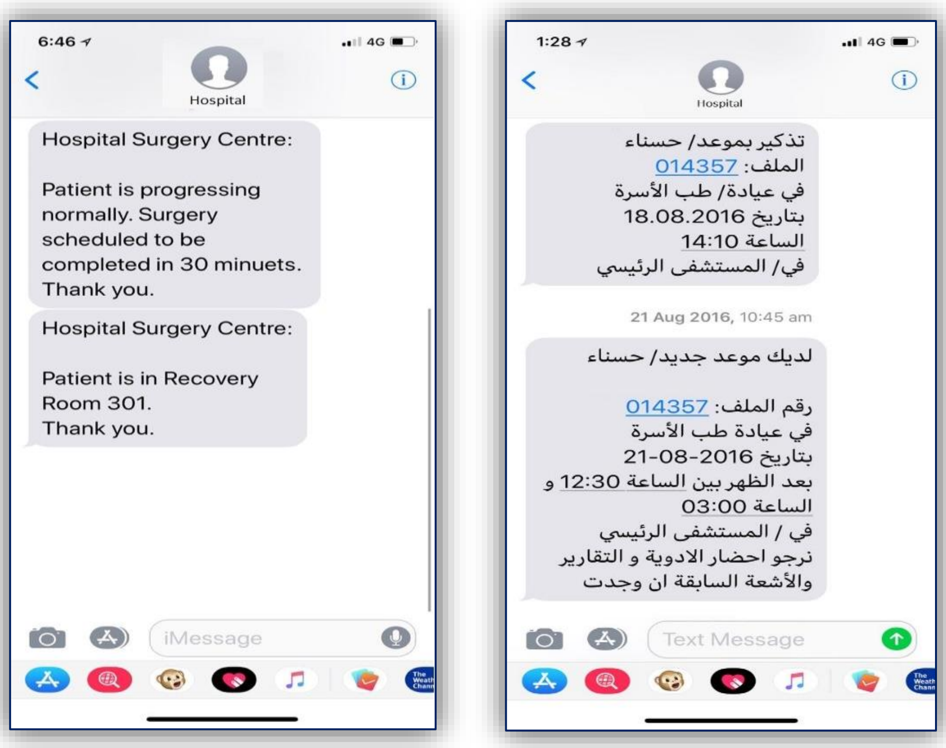


Figure 7.6 Interactive messaging and notification system for patients and their relatives

7.10.2 Mobile Wayfinding and Indoor Navigation

Hospitals and medical campuses are large and confusing facilities that have grown larger over time. Hospitals in Saudi Arabia have added more beds over recent decades, in order to meet the needs of the increased population. Mobile wayfinding and indoor navigation provide a fast solution to the issues of expanding and complicated healthcare environments for the benefit of patients, their families and hospital staff. With the use of information generated from RFID and ZigBee tags, wayfinding functions can provide the user with step-by-step directions superimposed on a map of the surrounding area. A patient can check in at multiple locations within a large hospital, and this system provides ease of navigation through simple visuals and arrows guiding the patient. Such a feature is shown in Figure 7.7a (left), with visuals improved by colour schemes, arrows and dotted lines showing specific paths to take, and a notification upon arrival. The design provides "ease of use", making it accessible to older users. It also ensures that nursing staff could find the fastest route between destinations, and teaches them the hospital layout with greater rapidity than under the traditional route of experience.

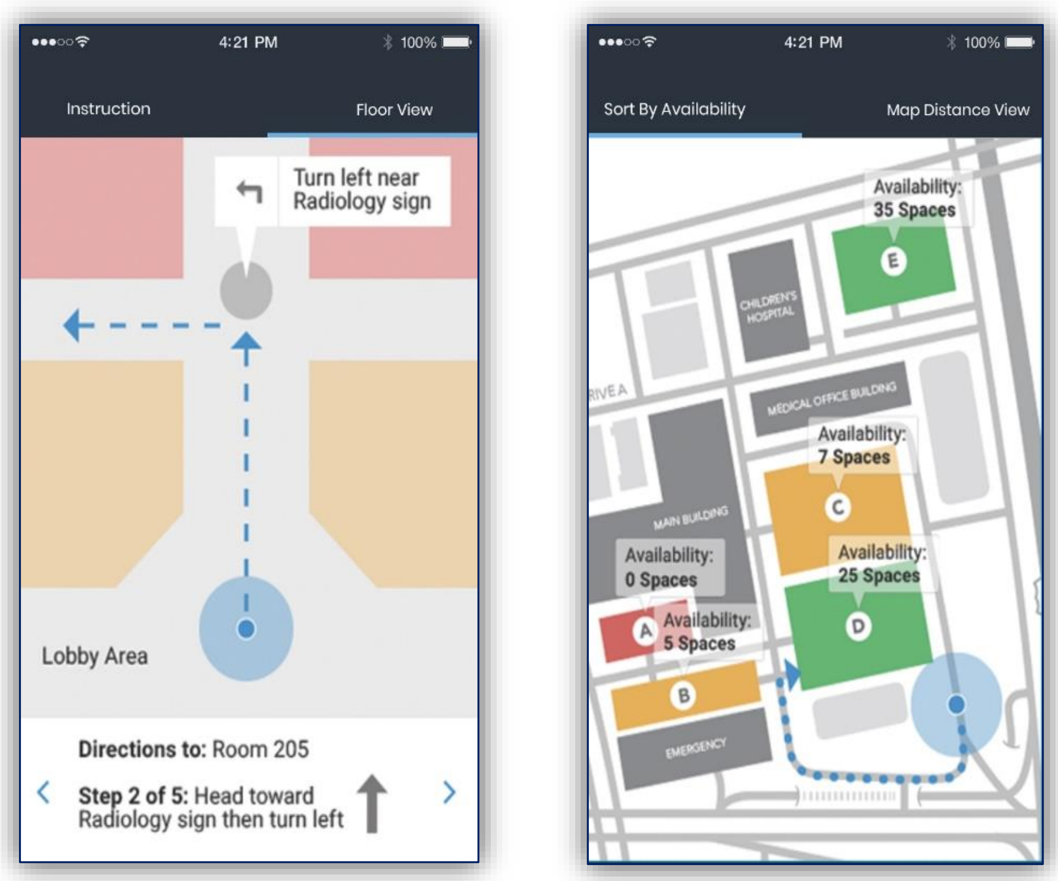


Figure 7.7a Mobile wayfinding and indoor navigation; Figure 7.7b Mobile wayfinding and parking assistance

The same features that allowed the patient to check-in and make appointments can provide this wayfinding functionality. It also improves the patient's personalised experience within the facility. Wayfinding can enable healthcare organisations to resolve common patients' complaints, which extend also to parking, as shown in the navigation features of Figure 7.7b (right). The parking function provides directions as well as the availability of spaces within each parking area.

This feature provides the added benefit of reporting and analytics on workflows for all people whose locations are tracked. This includes analysis on the amount of time individuals spend stationary while waiting for the next activity, or while engaging in an activity. With the reduction in missed appointments, lost revenues will be minimised, and staff will not be burdened by handling late appointments or directing patients.

7.10.3 Staff Tracking and Monitoring

Benefits of the RTTM system for hospital personnel include the ability to locate staff in real time, to analyse workflows and re-locate staff accordingly, to adjust staffing ratios based on workflow times, and to provide instant notifications for alerts or emergencies. Some of the specific ways in which the RTTM system provides these solutions are explained as follows.

Figure 7.8 shows a dashboard for several aspects of the tracking and monitoring of hospital personnel. The top bar gives an overview of the organisation's listed physicians, with pictures for familiarity and openness. The location of each physician is visualised in the blueprint of the hospital floor with different coloured dots representing the physician's location in real time. The particular physician under analysis for the remainder of the dashboard has his/her picture and name given in the upper left. A brief biography is listed, followed by the physician's patient load. This leads into the remaining graphics that can either support these loads or identify a way for improvement, possibly telling the administration that this physician can handle more patients. Average patient load is shown on a month-by-month basis, which would indicate the need to consider transferring some patients to other available physicians when needed. The chart to the bottom right shows average waiting time on a month-by-month basis. This chart can be compared or overlaid with the average patient load chart, as they cover the same months, and a correlation can be deduced from the results. The graphic on bottom left shows various circle charts for the physician's patients, in terms of demographics, age and geographical location. Graphics like these can help physicians achieve better mixing in patient types by the shifting of patients between physicians if one is found to have a concentration of a specific kind of patient.

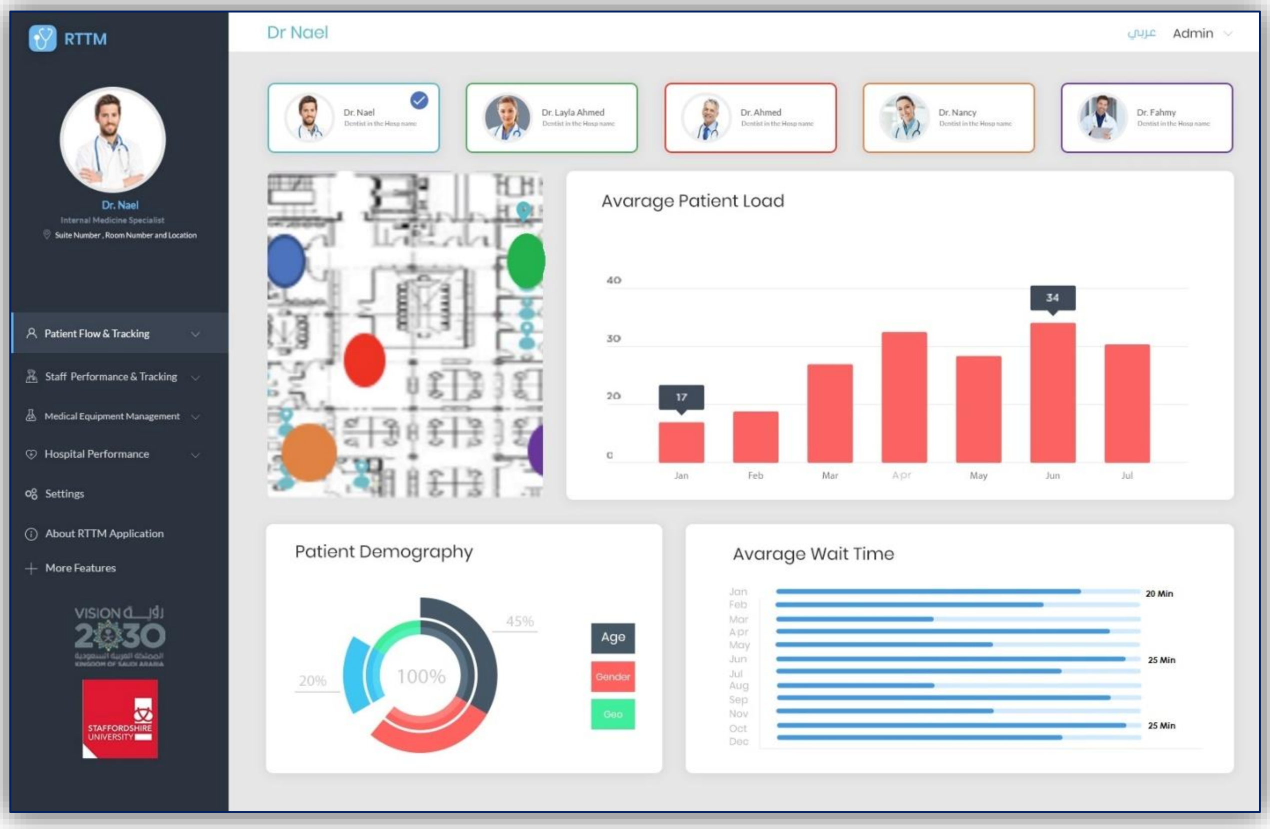


Figure 7.8 Hospital personnel tracking dashboard

Developments generated from the RTTM system include improvements in staff satisfaction; the elimination of manual documentation; the production of actionable intelligence, reports and analytics; the minimisation of variability in the patient care processes; and the reduction in response time to emergency calls.

Hospital staff can also take advantage of the interactive messaging and notification system in many ways. One method for improved workflow is by notification messages. These notifications would likewise be automated and derived from alerts fitting another set of pre-defined criteria. Besides updates on how far along patients are with various activities, hospital staff can be notified when patients are ready to be seen, thus eliminating time spent waiting for the nurse to notify them in person; and staff can be notified when they are needed by a patient for any alert they may have sent.

7.10.4 Medical Equipment Tracking and Monitoring

The real-time tracking and monitoring of medical equipment includes the locating of essential (critical care) equipment when needed, the ability to search and find equipment instantly, the ability to maintain equipment better by the monitoring of their statuses, the managing of inventory to better levels, as informed by automatic alerts, and the provision of real-time alerts on equipment conditions. This system can utilise a performance dashboard as shown in Figure 7.9, with device images and names. The map is visualising multiple devices, which would allow nurses to retrieve the needed equipment closest to their current location. Some useful metrics for visualisation here, would be the number of available assets in various working conditions, the performance rate, and the average rate for using a device in a certain clinic. Trends can then be spotted to ensure increased asset utilisation, and the reduction in shrinkage rates; this generally decreases costs over time.

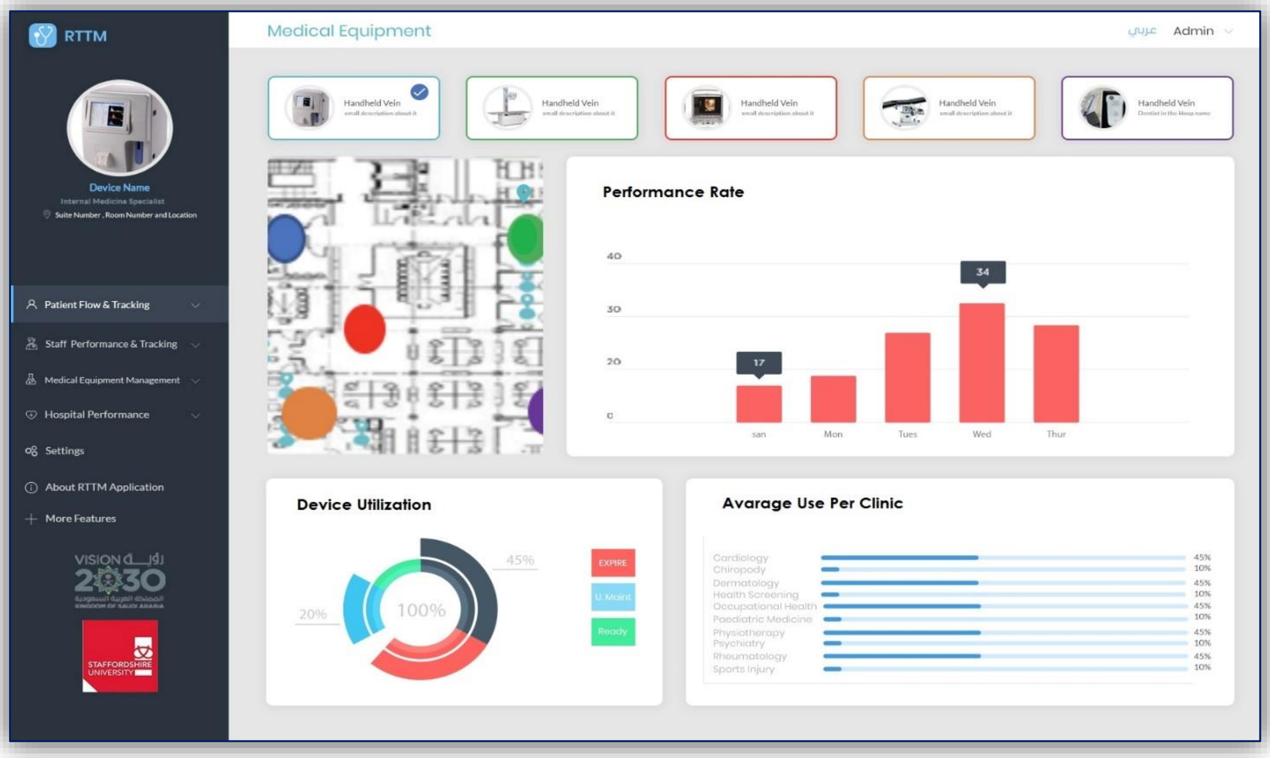


Figure 7.9 Medical Equipment tracking dashboard

The instantaneous access to medical devices also helps to improve ultimate patient outcomes and experiences, by reducing time and effort spent on searches, and improves reliability that inventory is consistently at standard levels. Additionally, the RTTM system allows for location histories of individual assets to be visualised and analysed, so that they can be relocated in the future for better proximity to expected point of use. The dashboards provided for asset visualisation produce optimal inventory quantity and location and visualisation of the equipment process cycle status. Improved workflow is another direct result of this system.

7.10.5 Infant Tracking and Monitoring

Infant protection can be enhanced through the RTTM system. The system designed for infant protection includes tamper alarms, exit alarms and out-of-unit alerts for immediate reaction by staff. Alerts are sent directly to caregivers and provide automation for the transfer of infants between various hospital locations. This smooths the workflow and retains the highest level of security, and thus the accountability, of the hospital. The parents of the infants increase their trust of the hospital by the constant ability to track the location of their infant. The system is shown in Figure 7.10 followed by the system symbols.

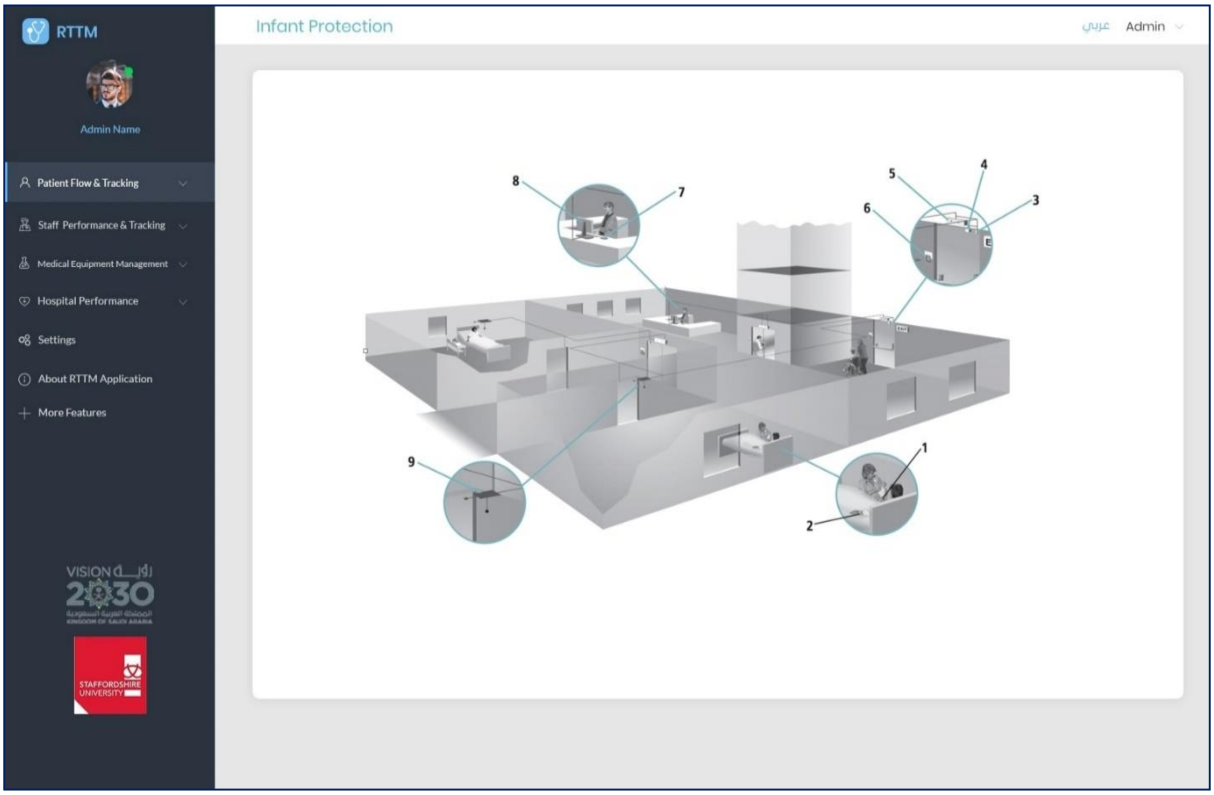


Figure 7.10 Maternity Unit and Infants protection

1	Baby tag	4	Magnetic door locks	7	Pager systems
2	Mother tag	5	Exciter	8	Controller PC
3	Door contacts	6	Keypad	9	Receive

The system uses matching tags for the mother and infant to eliminate misidentification, and it is reinforced by an alarm triggered if the infant is brought to the wrong mother. Several other reasons for alarms to sound include the following:

- An individual attempts to exit a protected doorway unauthorised with an infant
- No signal is detected by the infant's tag for a pre-determined amount of time
- The band is damaged or tampered with
- The tag has a low battery
- After an authorised exit, another individual enters through the protected doorway unauthorised with another infant

The system provides simple enhancement of a vital hospital function, and has the potential to greatly reduce patients' complaints and improve patient's trust.

7.10.6 Hospital Performance Dashboard

The hospital performance dashboard is the culmination of the analytics provided by the RTTM system and important insights are made available to hospital personnel. Figure 7.11 illustrates the capabilities of the performance dashboard.

The hospital performance dashboard shows variation in the performance. This graphic provides management with a clearer understanding of the visual representation of the RTTM system. Locations and status of tracked tags are visible with each floor separated and each type of tag listed. The tags are also divided, based on zones and type of individual or use (i.e., patient, infant, mother, staff, asset, etc.). The bottom graphics focuses on patient satisfaction, and medical equipment utilisation rate. The graphic up right is representing two admissions KPIs, which are bed turnover and the average length of stay.

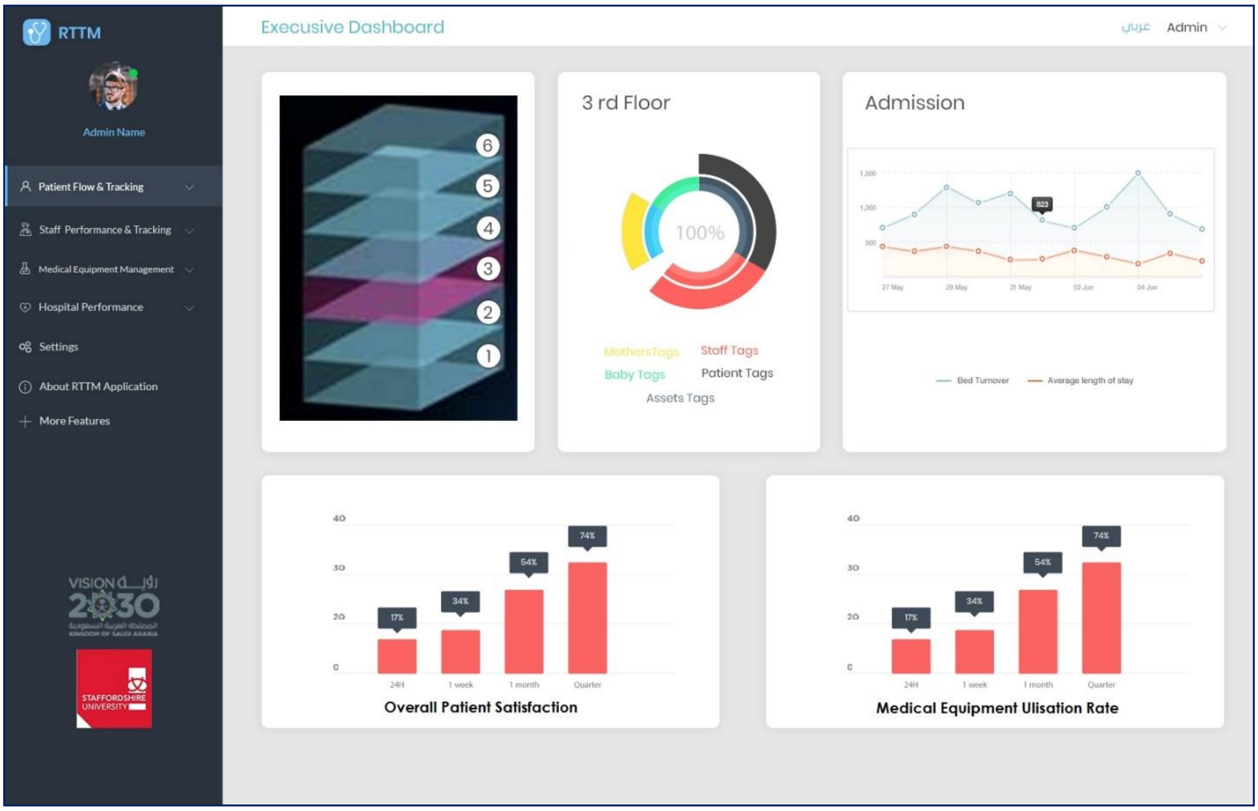


Figure 7.11 Hospital performance dashboard

Figure 7.12 shows a performance dashboard for Operating Rooms (OR) and various situations on the completion of surgeries or of other operating procedures. It uses data on the location of the set of individuals required for the operating procedure, in order to establish the operating status and expected time of completion. This can be compared with the standard time, and the results are colour-coded, based on being on time (green), delayed due to one staff delay (yellow) or delayed due to two or more staff delays (red). The statistics for % Complete and the amount of time delayed can help staff adjust their workflows, assist management in re-locating staff and analyse current trends so that delays are minimised in the future. Additionally, staff who consistently cause delays can be reported. Aggregated causes of delays can be analysed, so that they are minimised.

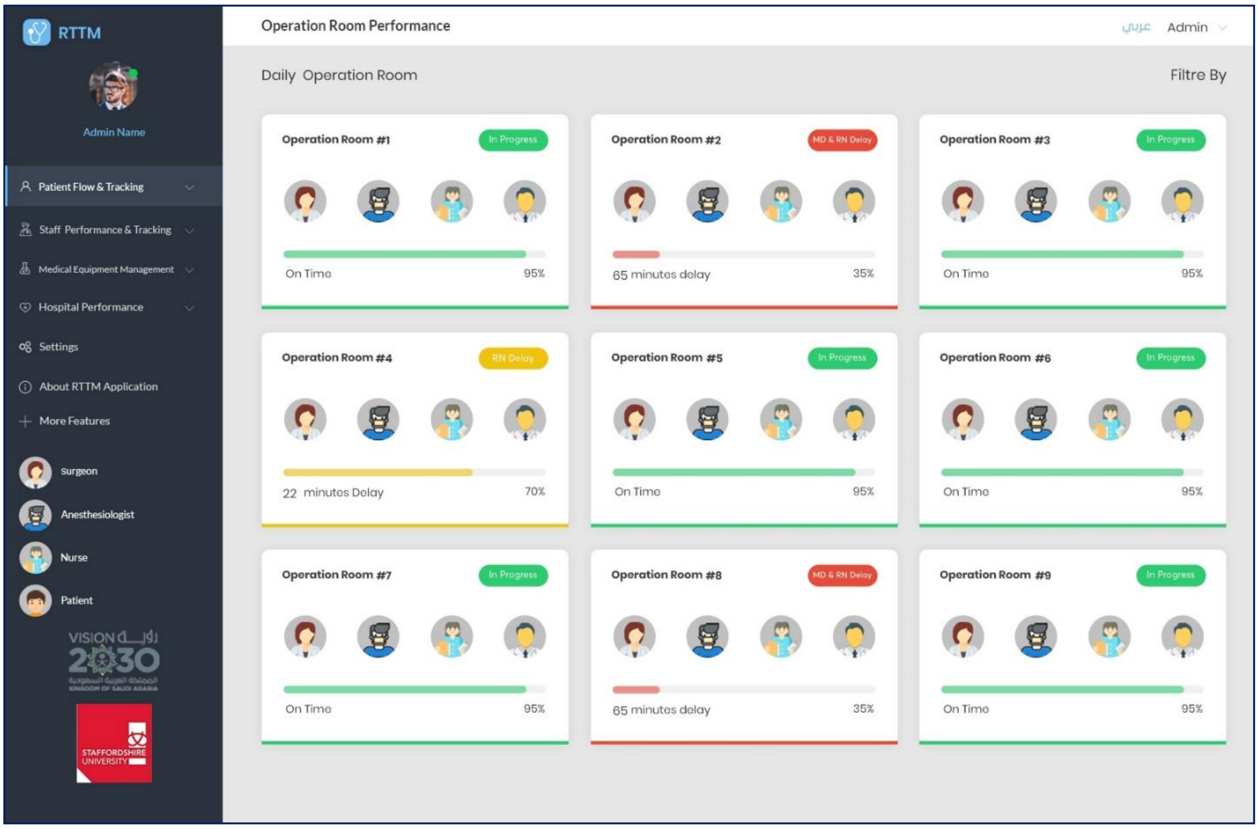


Figure 7.12 Operating Room Dashboard

7.10.7 Hospital Staff Training and Learning tools

As emphasised throughout this research, staff training is vital in the context of a new e-health system as they can become too complicated for some individuals without constant revision. Analysis by management, based on the performance dashboard, can direct future learning and adjust the focus for what their personnel must do to remain up-to-date in the future.

3D dashboards as shown in Figure 7.13 are ideal for the continued development of staff and in maintaining optimal utilisation of the new features introduced by the RTTM system. As this holistic framework has advocated, training should be continual, so that mistakes and delays are minimised. It also demonstrates the importance and value that the hospital places on its staff, thus improving general demeanour. A learning tools for staff also allow an organisation’s own members to observe the trends visualised through the dashboard, and to identify deficiencies in their own practices or attitudes. A learning tool connects the benefits of the RTTM system with the model of constant improvement. Many functions of the system have shown to result in more available time for hospital staff, meaning that more of their working time can be spent within the learning tool.

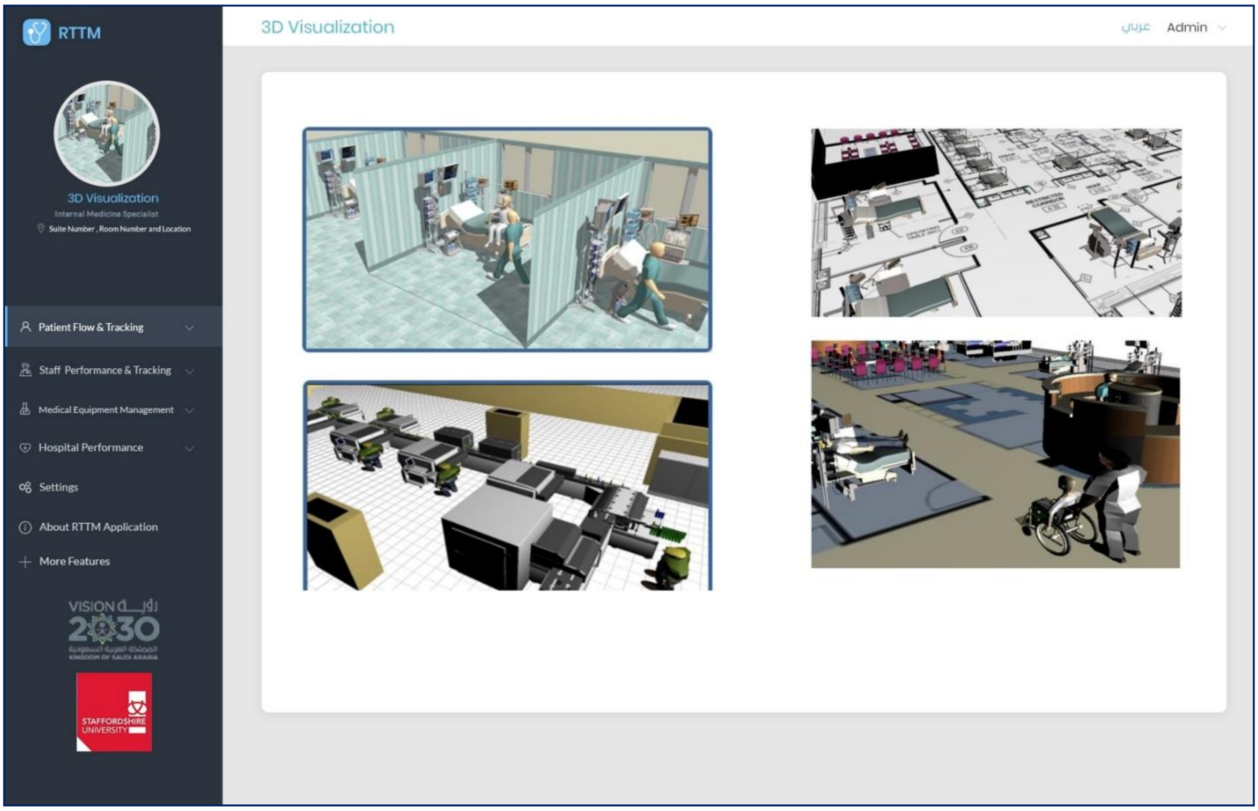


Figure 7.13 Hospital Staff Training and Learning tool

7.11 Conclusion

This chapter has discussed and integrated knowledge management and visualisation for an enhanced utilisation of the RTTM system to be implemented in healthcare organisations. Its benefits have encompassed the improvement in patient centric care, reduction in patient-oriented problems, knowledge of staff and asset locations and statuses, mobile wayfinding for patient satisfaction, enhanced infant protection, a hospital performance dashboard for powerful analytical insights, and the integration of a learning tool for hospital staff to maintain their up-to-date knowledge on the technology system and on medical developments. The next chapter will demonstrate the validation of the RTTM system using a panel of healthcare experts.

Chapter 8 Validation and Evaluation

8.1 Introduction

The previous chapter discussed knowledge management and knowledge visualisation for the RTTM system developed in this research. It also used the SECI model to explain various types of knowledge conversion, as relevant within the healthcare environment. The resulting graphical displays demonstrated that visualisation helped to show the dynamic nature of the RTTM system and the many ways in which it can assist in improving hospital workflows; and greater organisation-wide efficiency and performance.

This chapter builds on the previous chapters by defining validation and illustrating how previous chapters have achieved this need. Chapter 4 demonstrated validation of the holistic framework through the use of Communities of practice (CoPs), and workflow improvements in Chapter 6 supported the use of real-time tracking and monitoring technologies in hospitals. The remainder of this chapter is dedicated to the evaluation of the RTTM system using a diverse panel of experts in Saudi Arabia, satisfying a predetermined set of criteria. Diversity is satisfied by multiple roles within healthcare sector being represented (e.g., management, health professionals, IT and engineering) from three hospitals in Saudi Arabia. The results of this panel will be analysed, and recommendations derived from the results will thereafter be presented.

8.2 Validation

Validation is a primary means through which computerised system and applications are assessed for accuracy, reliability and for determining the model's predictive power (Beguería, 2006). Validation is defined as *'the process of determining the degree to which a model is an accurate representation of the real world from the perspective of the intended uses of the model'* (Oberkampf & Trucano, 2008). This practice therefore provides evidence of the degree of accuracy that can be validated by experiments. Validation addresses the assessment as follow:

1. Reliability of modelling processes
2. Consistency and relevance of the model to the conducted experiment
3. Influence of the experimental techniques on the measurements
4. Estimation of uncertainty in measurements.

8.2.1 Validation of the Holistic Framework by CoPs

This research demonstrated validation of the holistic framework through the use of Communities of practice (CoPs) in Chapter 4. CoPs were involved in the development and validation of the framework after the four contexts (technology, organisational, human and business) with several factors linked with each context which were based on the researcher empirical studies.

The researcher formed the CoP, and this met on a regular basis for the discussion of various issues and challenges. In this way, collective knowledge and experiences guided the research in achieving its objectives. In the context of validation, the CoP performed the following:

1. Reviewed the current RTLS technologies and applications, and their advantages and disadvantages.
2. Identified the most important user requirements.
3. Assessed and compared different indoor tracking and monitoring technologies.
4. Provided a model for choosing the appropriate technologies that meet the hospital's needs, standards and expectations in achieving the goals set.
5. Validating and refining the developed framework (2nd version).

Additionally, the CoP utilised in this research validated the combination of RFID and ZigBee technologies for integrated information systems in Saudi healthcare. The CoP agreed that the transfer of real-time information and the visualisation of various entities were possible through the developed RTTM system. The CoP also agreed that the RTTM system would improve management systems and provide more effective decision support systems, and that the technologies were relatively cost-effective in comparison with all available technologies.

In a similar manner, Chapter 5 utilised a questionnaire with more than 200 usable responses to validate the user requirements as defined by the CoP and, furthermore, that the user requirements would be sufficiently met by the holistic framework and the resultant RTTM system. Analysis of the results of the questionnaire led to a second refinement (and third version) of the holistic framework.

8.2.2 Validation of Tracking and Monitoring Technologies by Proof of Concept Trail Experiments

Oberkampf & Trucano (2008) indicated that '*Validation is not a procedure for testing scientific theory or for certifying the "truth" of current scientific understanding .... Validation means that a model is acceptable for its intended use because it meets specified performance requirements.*' Experiments can be used to validate a model (Oberkampf & Trucano, 2008). Therefore, the validation of the RTTM system that was developed in Chapter 7 was undertaken by the experiments that were conducted and analysed in Chapter 6.

Chapter 6 provides details on the workflow improvements process and an analysis of the results. Workflow scenarios were simulated using parameters within the hospital of interest to define the current workflow bottleneck times, then relocated one factor (i.e., staff, patients and assets) at a time while keeping the parameters constant, and the new workflow bottleneck times were calculated. The simulation scenarios results found that all workflow bottleneck times were minimised.

As the workflow simulation of revised locations of people and resources was only valid if the technology was accurate and efficient, the first trail experiment addressed the concern of accuracy. ZigBee equipment was quickly installed in the laboratory, and tags attached to personnel for tracking and monitoring their locations and statuses. As shown with the laboratory diagram and described in the results (Section 6.8.3), the experiment found the constant movement of the subject to be tracked with precision. Since the workflow simulation was similarly valid only if it improved workflow times, determining the times for hospital personnel to locate resources was the focus of the second experiment. This experiment used a real hospital for proof of concept setting to compare the time required of hospital staff in locating other staff members and various pieces of medical equipment. The results are also shown graphically and analysed in the same section (Section 6.8.3), with current practice needing 5 to 10 minutes for hospital personnel to locate a specific staff member, while the use of real-time tracking and monitoring technologies allowed the times to be revised to a range between 2 and 3 seconds. Similarly, current practice for staff to locate medical equipment required even more time, ranging between 11 and 20 minutes; this range was once again quelled greatly to the same range of 2 to 3 seconds. This new range was logical, as the system employed the same technology for the locating of both staff and medical assets. It also showed a marked decrease that clearly validates the intended use of the RTTM system in the real world. Combined, the two experiments validate the accuracy (1st Trail Experiment- Laboratory) and efficiency (2nd Proof of Concept Hospital Experiment) of the RTTM system.

8.3 Evaluation of the RTTM System by a Panel of Experts

Evaluation of a model refers to the assessment of its suitability with respect to user requirements (Overhage et al., 2010). Meeting the needs of users can be evaluated through their preliminary involvement in the evaluation process. In this research, a panel of ten experts was therefore used in order to evaluate the system and to derive any future improvements and recommendations. According to Nielsen and Molich (1990), aggregate of five participants can indicate more than 80% of the issues in an evaluation study, and ten participants can indicate almost all of the issues as seen in Figure 8.1 (Nielsen & Molich, 1990).

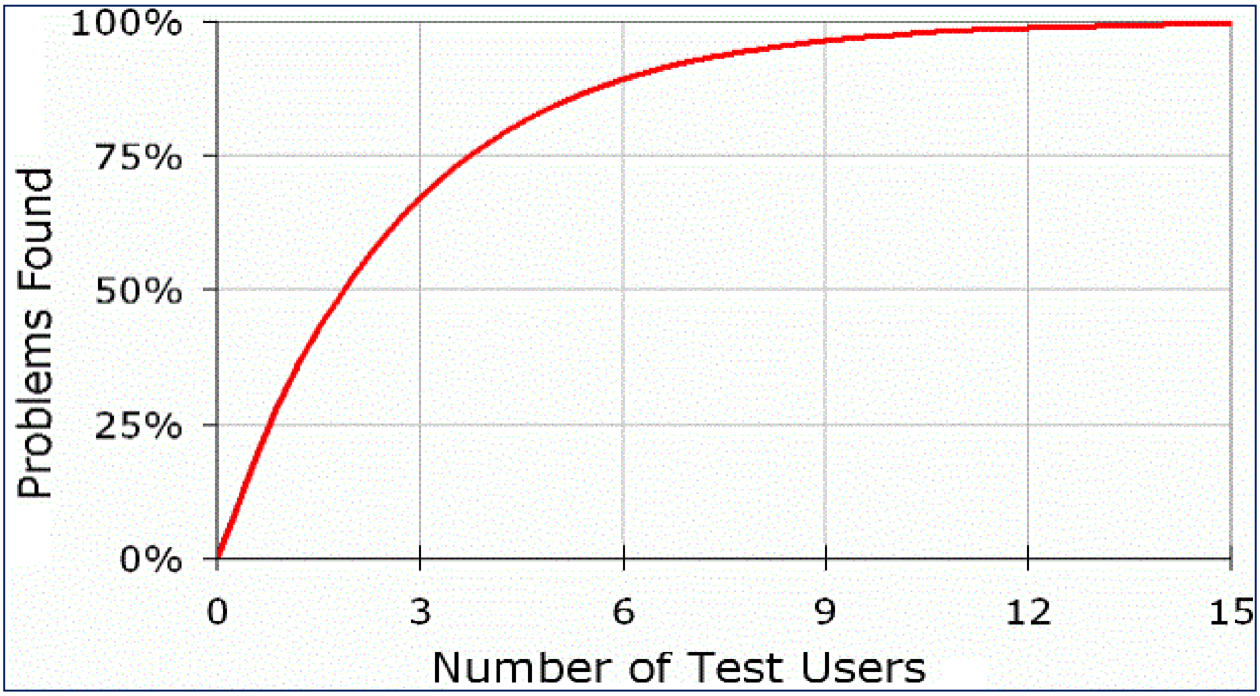


Figure 8.1 Nielsen usability model. Source: www.nngroup.com

The panel participants were selected based on fulfilment of the following set of criteria:

- Currently working in a Saudi healthcare organisation.
- Have at least five years of relevant experience, such as in healthcare or IT.

The aim, while searching for qualified individuals, was to maintain diversity of experience in information technology systems within Saudi healthcare, while locating a relatively equal number of experts from each of three Saudi hospitals. This aim was satisfied as can be seen in Table 8.1. The table summarises the profiles of the participants, distinguished by hospital. One participant worked in management, five as health professionals, three as heads of IT departments, and one in engineering. The five health professionals also spanned much of the hospital environment, including two nurses, two doctors and one head of the e-health department. Additionally, the number of years of experience ranged from 5 to 13, providing a diverse set of experiences from which to approach an information technology system.

Table 8.1 Participants' Profiles

Hospital	Participant's Position	Participant's Background	Years of Experience
1st Hospital	Project Manager of HIS	Management	11
	Nurse	Health Professional	6
	Head of IT department	IT	5
2nd Hospital	Head of e-health department	Health Professional	13
	Doctor	Health Professional	9
	Head of IT department	IT	7
3rd Hospital	Head of IT department	IT	8
	Nurse	Health Professional	12
	Doctor	Health Professional	10
	Biomedical Engineer	Engineering	9

After the participants were selected, a workshop was held via video conference through Cisco WebEx, to facilitate the RTTM system evaluation. The video conference platform allowed for all participants to observe researcher's presentation in the same time. The workshop was divided into three parts. In the first part, researcher thoroughly explained the aims and objectives of the research to the participants. In the second part, the researcher presented the developed RTTM system, and discussed its features and benefits. Questions were answered in this part for clarification on any aspects of the RTTM system. In the third part of the workshop, the system was assessed and evaluated individually, using the questionnaire and criteria as defined and explained in the next section.

8.4 Design of the Evaluation

The evaluation for the panel of experts was designed to gain the best possible feedback, to obtain assurance that the RTTM system is appropriate for its intended uses, and to judge whether it will work as expected. The evaluation was constructed through the use of the most relevant and encompassing criteria, to test all the important aspects of the developed RTTM system. Table 8.2 shows the assessment criteria, with definitions provided for each criterion. The definitions are adapted from the sources provided for the context of this research.

Table 8.2 Real-Time Tracking and Monitoring (RTTM) Evaluation Criteria

Evaluation Criteria	Definition
Ease of Use	The degree to which an expert believes that using the RTTM system is free of effort (Anny Leema & Hemalatha, 2015).
Usefulness	The degree to which an expert agrees that using the RTTM system would enhance the patient-centric services (Wamba & Ngai, 2012).
Hospital Decision-Making Support	The degree to which an expert believes that the RTTM system will provide support for intelligent decision making in hospitals (Sperandio et al., 2014).
Comprehensiveness	The degree to which an expert believes that the RTTM system is complete and includes everything that is necessary (Ajami & Rajabzadeh, 2013).
System Functionality	The degree to which an expert perceives that essential functions are achieved through the RTTM system (Liu et al., 2014).
Intention to Use	The degree to which an expert believes the healthcare stakeholder will use the RTTM system (Lambrou et al., 2014).

The criteria as defined in Table 8.2 were the key factors evaluated by the panel of experts on a 5-point Likert scale. This scale is illustrated in Table 8.3, which shows that a score of 5 is desirable and 1 is undesirable. Each of those criteria gives definitions for each rating, based on the definitions provided for each criterion in Table 8.2.

Table 8.3 RTTM system Assessment Scale

Assessment Criteria	Assessment Scale				
	5	4	3	2	1
Ease of Use	Very easy to use	Easy to use with little explanation needed	Easy to use but required explanation	Not easy to use but could be used with explanation	Not at all easy to use
Usefulness	Very useful	Useful	Useful but may need some improvement	Not very useful but it could be considered for use	Not at all useful
Decision-Making Support	Provided a lot of support	Provided support	Provided some support but there would be a need for other tools	Did not provide enough support but it could be used as an extra tool	Did not provide support
Comprehensiveness	Very comprehensive	Comprehensive	Fairly comprehensive	Not sufficiently comprehensive	Not at all comprehensive
System Functionality	Very efficient	Efficient	Efficient but with some difficulties	Not efficient	Not at all efficient
Intention to use	Very likely	Likely	Quite likely but would require some modifications	Not likely unless there were major modifications	Not at all likely

8.5 Analysis of the Results

This section provides visual representations of the results for the panel's evaluation of the RTTM system for analysis. The results from the 10 participants were aggregated and separated in various ways to allow for analysis for different sub-groups within the panel. The aggregated results are shown in Figure 8.1, with all 10 participants' evaluations of the system shown by the ratings visualised by the points on the hexagon in the diagram.

Figure 8.2 Real-Time Tracking and Monitoring (RTTM) Assessment Criteria

The overall evaluation shows that all criteria received positive marks, with the scores ranging from 4.4 for Usefulness and Comprehensiveness to 4.9 for Intention to Use. This indicates that the average response agreed on the suitability of the RTTM system in meeting the various needs and user requirements in a healthcare setting. Support is therefore strong for the system, and the initial look at the overall evaluation shows agreement on all criteria. The analysis will focus on each individual criterion, followed by the separation of the participants by hospital and by role in healthcare.

8.5.1. Ease of Use

The criterion 'Ease of Use' evaluates the degree to which the expert believes the RTTM system is effortless (Anny Leema & Hemalatha, 2015). As can be seen by the chart in Figure 8.2, all participants consider the system to be either 'very easy to use' or 'easy to use with little explanation needed.' The average rating on the 1-5 scale is 4.8, which is very high. Furthermore, 8 of the 10 participants agreed that the system was very easy to use, indicating that the belief in the effortlessness required of this RTTM system is high. Ease of use is critical in ensuring the success of the RTTM system; and based on the results of this panel evaluation, it is satisfied.

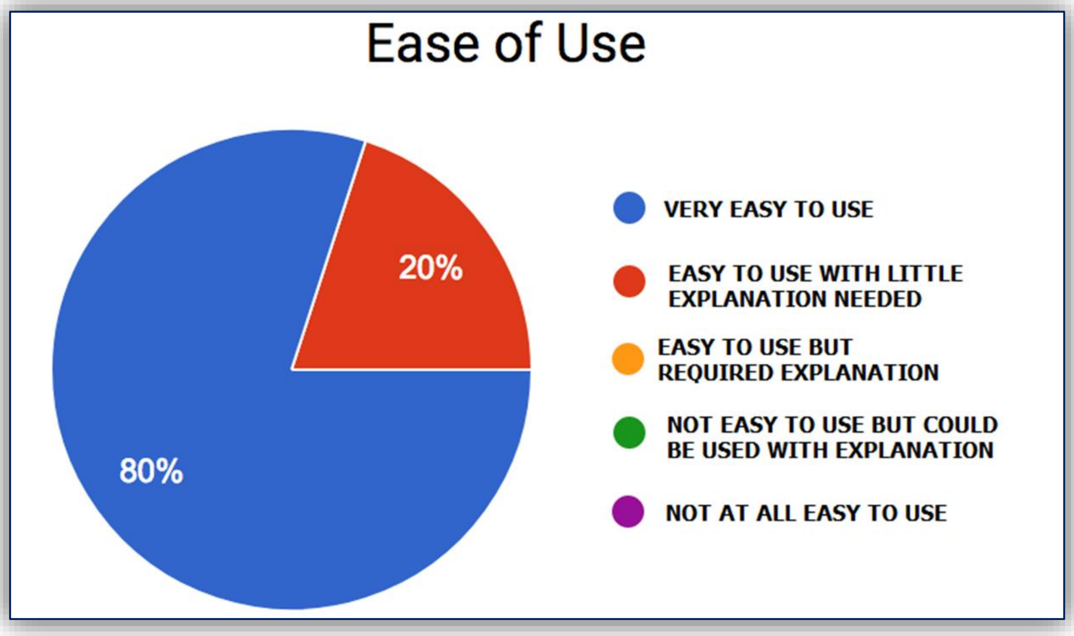


Figure 8.3 Panel evaluation of Ease of Use

From this, it can be concluded that the RTTM system will be well-understood by healthcare stakeholder, and it can be expected that the average healthcare worker will not find the system difficult to use.

8.5.2. Usefulness

The criterion 'Usefulness' evaluates the degree to which the expert believes that use of the RTTM system will enhance job performance for healthcare practitioners (Wamba & Ngai, 2012). Figure 8.3 shows the distribution of results from the 10 participants, with this receiving an average mark of 4.4 out of 5. Although, 80% of the participants agreed that the system is either 'useful' or 'very useful', this criterion found two participants who consider that the system is 'useful but may need some improvement'. With the information given in Figure 8.3, it can be concluded that most of participants agreed that the RTTM system would be useful to the healthcare workers.

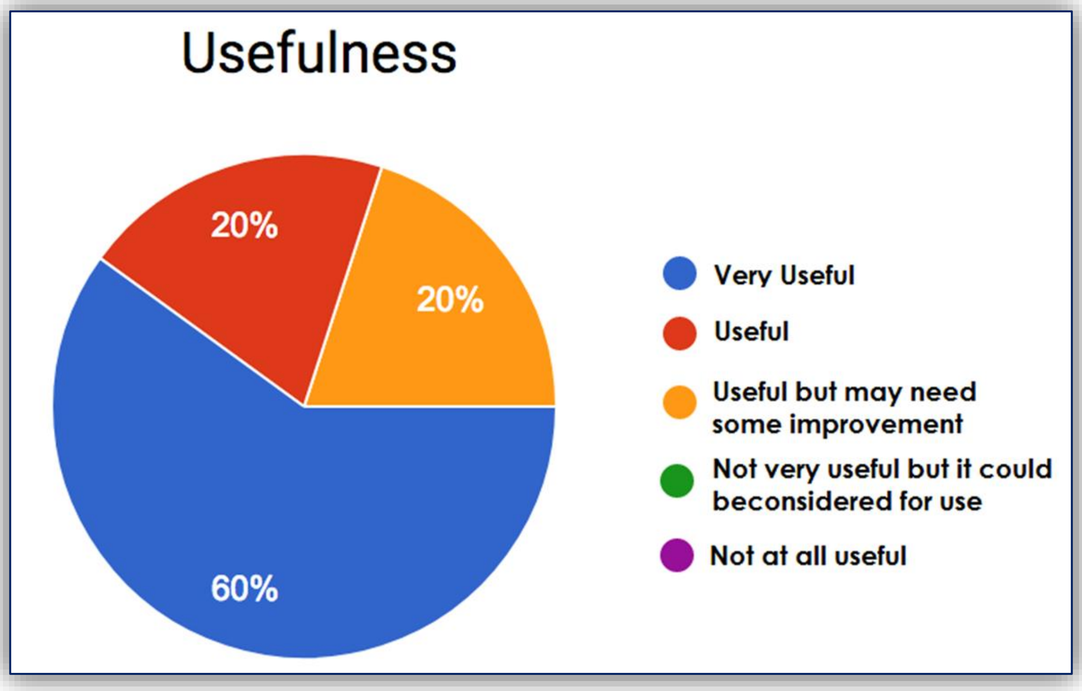


Figure 8.4 Panel evaluation of Usefulness

8.5.3. Hospital Decision-Making Support

The criterion 'Hospital Decision-Making Support' evaluates the degree to which the expert believes that the RTTM system will provide support for intelligent decision making in hospitals (Sperandio et al., 2014). With an average mark of 4.7 out of 5 and all participants agreeing that the RTTM system provided support, this is a strong factor and shows great approval for the system. As shown in Figure 8.4, 7 of the 10 participants agreed that the RTTM system 'provided a lot of support' for hospital decision-making. No participants believed that other tools would be necessary after the implementation of this system; importantly, no participants believed that IT was required for use as an extra tool. Thus, this criterion is satisfied by the evaluation.

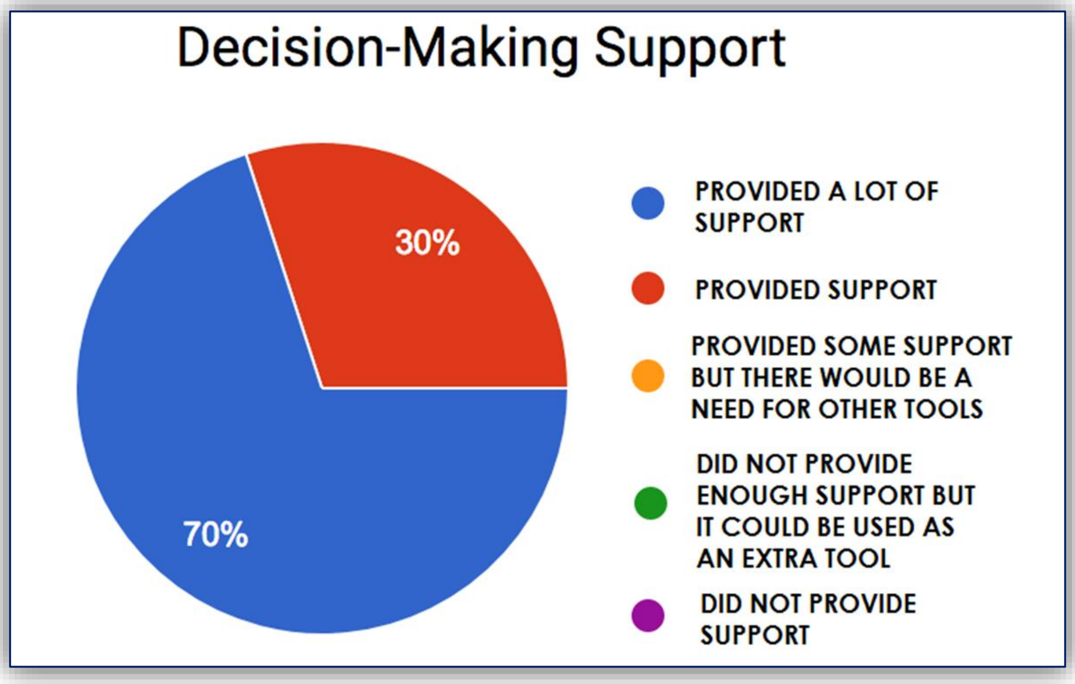


Figure 8.5 Panel evaluation of Decision-Making Support

The RTTM system is designed to meet the needs of management (i.e., decision makers within a healthcare organisation), so success in this criterion demonstrates that the system sufficiently supports hospital decision makers.

8.5.4. Comprehensiveness

The criterion 'Comprehensiveness' evaluates the degree to which the expert believes that the RTTM system is complete and includes everything that is necessary; or, in other words, the degree to which the system fulfils all user requirements within the context of healthcare (Ajami & Rajabzadeh, 2013). As Figure 8.5 shows, the results are precisely the same as for Usefulness, with the 4.4 average mark and 60% of the participants agreeing that the system is 'very comprehensive'. Most of the user requirements in healthcare are therefore believed to be covered by the RTTM system, per the beliefs of the panel. Two of the participants consider the system to be 'fairly comprehensive', indicating points of future improvement that will receive more focus in the section on recommendations.

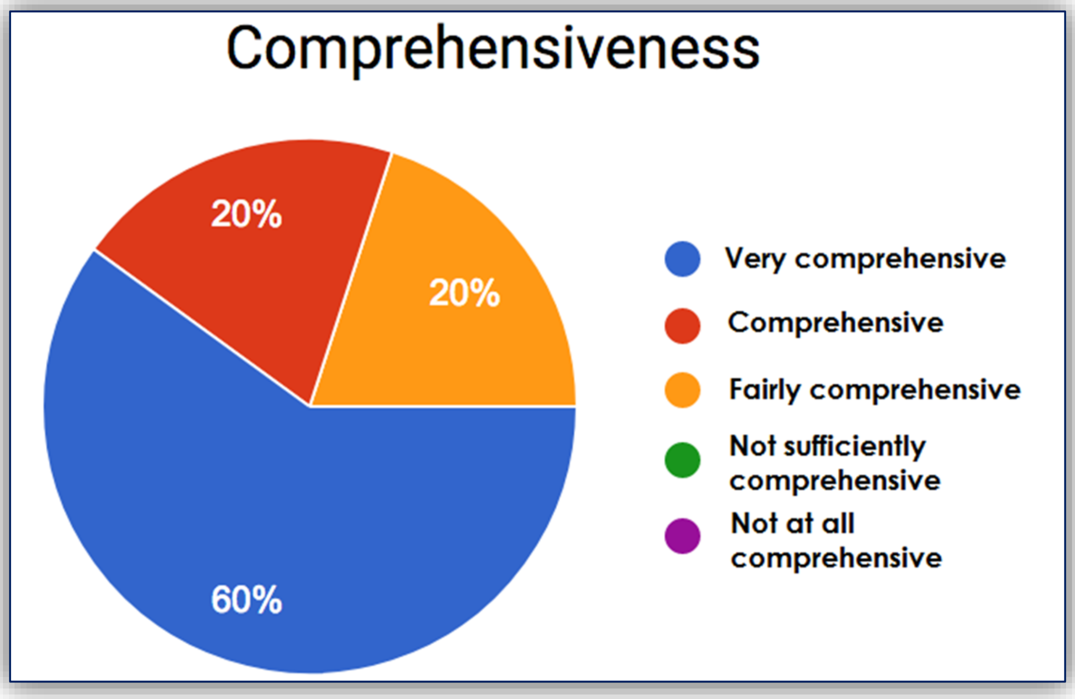


Figure 8.6 Panel evaluation of Comprehensiveness

8.5.5. System Functionality

The criterion ‘System Functionality’ evaluates the degree to which the expert perceives that essential functions are achieved through the RTTM system (Liu et al., 2014). Figure 8.6 shows that 90% of the participants (9 out of 10) agreed that the system either ‘very efficient’ or ‘efficient’. The average mark for System Functionality is 4.5 out of 5. Only one of the participants believed that the system was ‘efficient but with some difficulties’. The possible difficulties considered by the panel expert will be brought forward in the recommendation section.

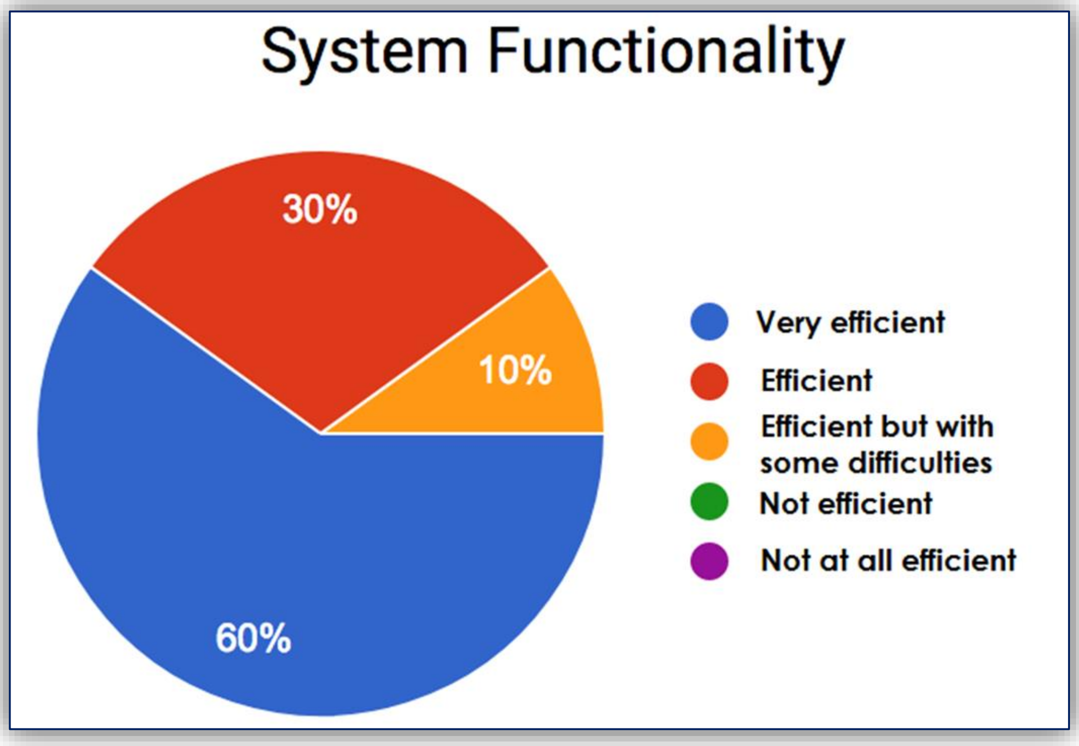


Figure 8.7 Panel evaluation of System Functionality

System functionality is vital to the acceptance of the RTTM system by staff in the Saudi hospitals. Due to the positive responses, it is unlikely that healthcare staff will find this system non-functional.

8.5.6. Intention to Use

The criterion 'Intention to Use' evaluates the degree to which the expert believes the healthcare stakeholder will use the RTTM system (Lambrou et al., 2014). This criterion received the most overwhelming support from the panel of experts, with 9 participants agreeing that stakeholders will be 'very likely' to use the RTTM system and 1 participant believing that stakeholders will be 'likely' to use it. The average mark is therefore 4.9 out of 5 for Intention to Use, with the results shown in Figure 8.7.

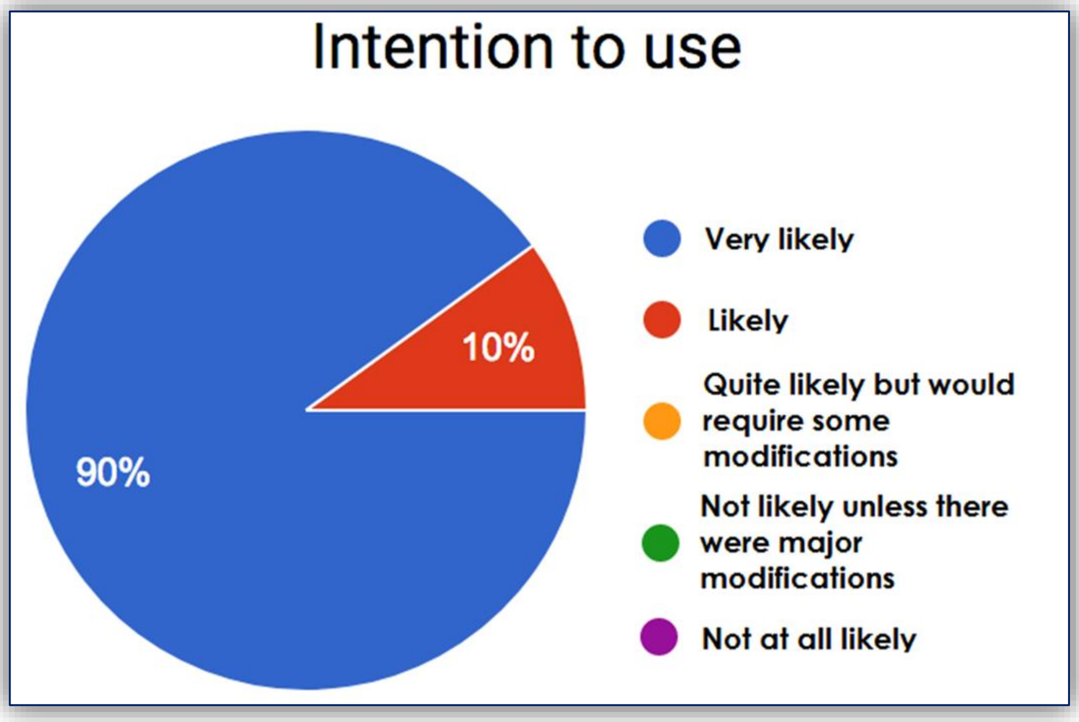


Figure 8.8 Panel evaluation of Intention to Use

The intention of healthcare decision makers to use the RTTM system is an essential component of the framework, as it determined whether or not it will be used at all. The most likely explanation for this criterion receiving the greatest support is due to Saudi healthcare technologies not currently meeting demands, so the probability that stakeholders would choose this system to improve their organisation's performance is high.

8.5.7. Separation of results by hospital

It is clear from Figure 8.8 that the use of three hospitals for the panel of experts provided the benefit of diversity. Hospital 3, from which 4 of the 10 experts were found, responded with all marks of 5. An important point here is that the background of these four participants included IT, health professionals, and the one engineering expert. These four participants also possessed experience ranging from 8 to 12 years, indicating no lack of expertise. The other two hospitals were more critical, though no hospital averaged a score for any criterion of under 4.0. The primary benefit of the graphic of Figure 8.8 is to illustrate the variation based on location, though more insights are available from deconstruction by healthcare background.

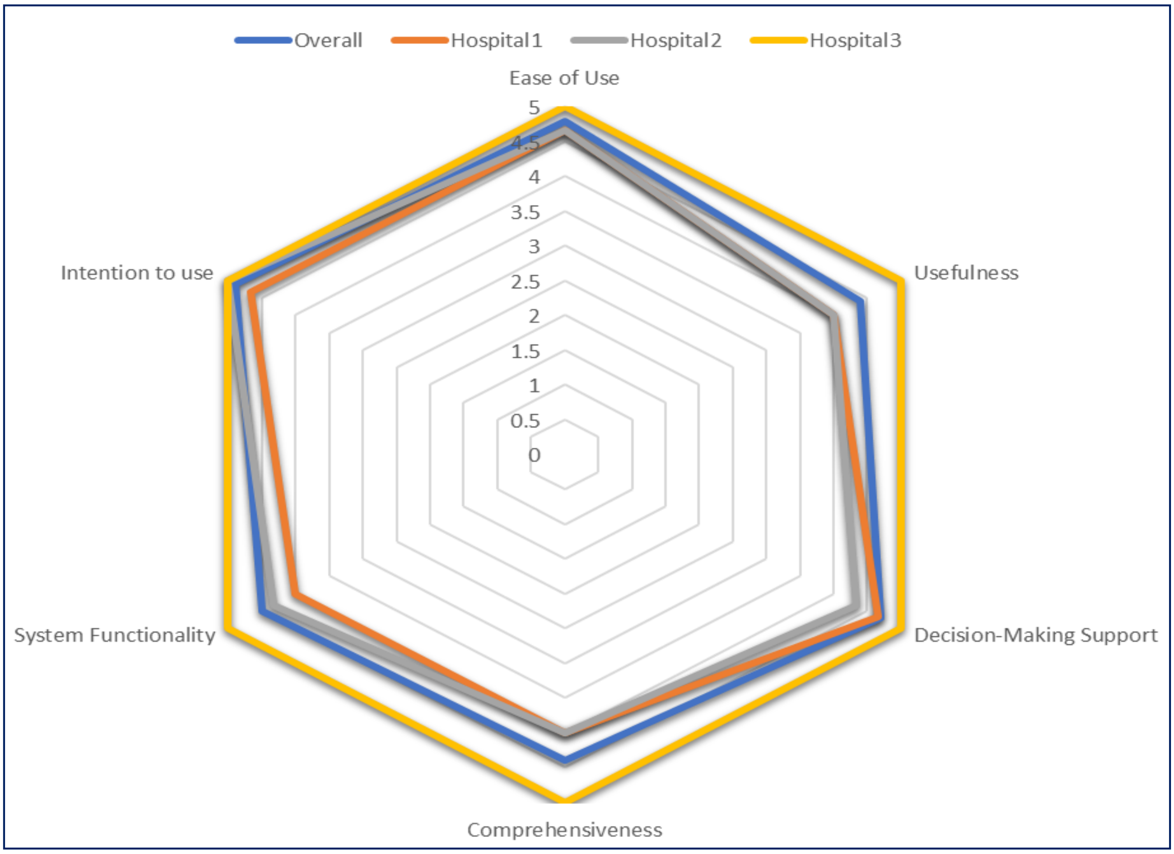


Figure 8.9 Overall evaluation of the system based on hospitals

Generally, there were no overwhelming differences between the hospitals, especially considering the complete approval by Hospital 3. This graphic mostly shows how Hospitals 2 and 3 were most influential in demonstrating any possible deficiencies in the lowest criteria, namely Usefulness and Comprehensiveness.

8.5.8. Separation of results by healthcare background

This section provides some of the most beneficial insight as it links the identified deficiencies with the role of the participants. As seen in Figure 8.10, healthcare background plays a role in the evaluation results. The results with the greatest deviations from the means are logically those for the roles with only one participant. This includes both management, who only answered with marks of 5; and engineering, who was minimally critical of Ease of Use, System Functionality and Comprehensiveness. These three criteria are logical to receive slightly lower marks from an engineer, who is aware of the complexities of a technology system. As for the participant in management, the consistently high marks are due to strong belief in the system as a whole. The remaining participants, which comprised 80% of the responses, are much more closely aligned with the overall averages, though IT staff were generally more critical of the system than were healthcare professionals. As this is a technology system, the responses of the three IT participants are very important. The perceived ability of IT to train healthcare professionals on this system is critical for its ability to achieve success.

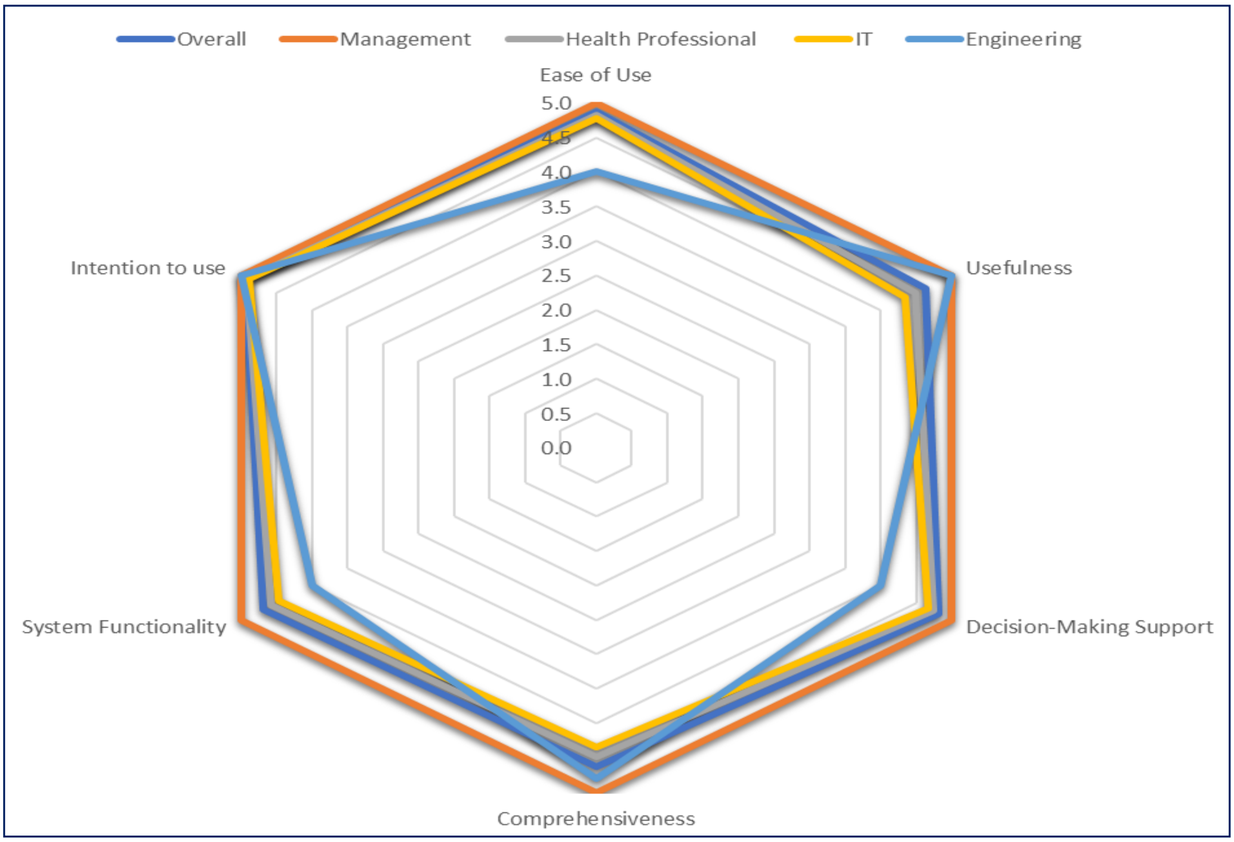


Figure 8.10 Overall evaluation of the system based on participants' roles

8.6 Recommendations

As the purpose of the evaluation through the use of a panel of experts was to determine the suitability of the RTTM system in the context of healthcare, any responses indicating recommendations are worthy of focus for future improvements. Based on the feedback from the participants, there were two recommendations:

- One expert suggested expanding the RTTM system to be a central system operated by MoH.

- One expert suggested that the RTTM system extended to include more features, such as monitoring and notifying hospital management when critical drugs are in short supply.

Both recommendations will be considered in future work. Additionally, these recommendations can best be achieved through constant evaluation and improvements of the implemented system in its preliminary stage, through the proper evaluation of the user requirements in the context of the healthcare organisation under question, ensuring that the organisation's complete needs are met.

8.7 Conclusion

This chapter has demonstrated how the holistic framework and the RTTM system have been validated through the use of CoPs, the questionnaire and the proof of concept experiments. Furthermore, this chapter has demonstrated evaluation of the RTTM system by a panel of experts within the field of healthcare through the spanning criteria of ease of use, usefulness, hospital decision-making support, comprehensiveness, system functionality and intention to use. The evaluations have been analysed the RTTM system from the perspectives of experts, the hospitals and the healthcare backgrounds. This evaluation has provided insights on the diversity of belief provided by the hospitals and the expanded experience incorporated through the use of various healthcare backgrounds, including management, health professionals, IT and engineering.

The panel of experts indicated that the RTTM system was generally acceptable. The system was found to be easy to use, useful, and comprehensive. It supported decision making by hospital management, was efficient, generated a high intention to use it, and encompassed the geographical locations and the healthcare backgrounds of interest. As the holistic framework and RTTM system have been validated for Saudi healthcare through various forms of validation and evaluation, this research can come to a conclusion in terms of its contributions to knowledge, limitations, challenges, and insights into future work as demonstrated in the final chapter.

Chapter 9 Conclusion and Future Work

9.1 Introduction

With the RTTM system evaluated by a panel of experts, this research now turns to its conclusion and raises ideas for future work. This chapter presents the conclusion of this research by summarising the research and making explicit its various contributions to knowledge. These contributions are compared with the aims and objectives given in Chapter 1, to show the ways in which they have been fulfilled. Furthermore, the limitations and challenges encountered during this research are outlined, with possibilities for future work and additional research identified based on these limitations and on insights gathered throughout this research.

9.2 Research Summary

- **Chapter 1 (Introduction)**

This chapter began by introducing the motivation behind this research, which was founded in the challenges observed in Saudi Arabian healthcare. The aim was stated as the proposal and development of a novel Smart e-Health system for tracking and monitoring staff, patients and medical assets to assist in healthcare decision-making in Saudi Arabia, with focus given to RFID and ZigBee technologies. The objectives included:

1. A literature review that addressed
    a. The challenges existing in Saudi healthcare.
    b. The use of indoor positioning and tracking technologies in healthcare.
    c. Knowledge management concepts for visualisation purposes.
2. A survey and use of a Community of Practice (CoP) of Saudi multidisciplinary healthcare professionals.
3. The development of a holistic framework for tracking and monitoring in the Saudi healthcare environment.
4. The development of a real-time tracking and monitoring (RTTM) system based on the SECI model, knowledge management and visualisation concepts.
5. The validation and evaluation of the proposed system using a panel of experts.

As this conclusion will show, the objectives have been met through various contributions to knowledge. The remainder of the first chapter outlined the structure and strategies of this research.

- **Chapter 2 (Healthcare Challenges)**

To expand on the motivation for this research and elucidate its need, the second chapter provided several important challenges in Saudi healthcare. These included patient misidentification, waiting time, patient flow, healthcare workforce numbers, physicians' punctuality and medical equipment availability. The Saudi healthcare system was then discussed in terms of its demographics and economic trends, followed by an overview of the components of healthcare and e-Health, with an emphasis on their status in Saudi Arabia, and integrated with the recent Saudi Vision 2030.

- **Chapter 3 (Using Technology to Tracking & Monitoring Patients, Assets and Staff)**

This chapter outlines the specific technologies available for indoor real-time locating and tracking purposes, discussing the relative advantages and disadvantages of each. These technologies included RFID, ZigBee, Bluetooth, cameras, infrared, WLAN/Wi-Fi, near-field communication (NFC) and ultra-wideband (UWB). It was concluded, through an analysis of RFID and ZigBee technologies, that these two choices could form an integrated real-time tracking and monitoring technology system that can support the healthcare system in Saudi Arabia. The importance of evaluating and selecting an appropriate system in the context of the healthcare organisation was discussed.

- **Chapter 4 (Development of a Holistic Framework)**

A holistic framework was developed and refined in this chapter, with the structure of the framework and a holistic approach outlined from a literature search of factors that assist in selecting appropriate RTLS in hospitals environment. The Information System Strategy Triangle (ISST) and Human, Organisation and Technology-fit Factors (HOT-fit) frameworks were discussed and integrated to form the holistic framework that encompassed four contexts: technology, organisational, human and business. After overviewing these contexts with respect to an integrated RFID/ZigBee system, a tracking and monitoring adoption strategy was developed through the adaptation of Cresswell et al.'s (2013) 10 key considerations in the HIT lifecycle. Change Management was then introduced, to understand the best approach of managing change. A Community of Practice (CoP) was then formed with Saudi multidisciplinary healthcare professionals, in order to assist this research. Using the expertise and collaboration of the CoP, the adoption strategy adopted the following steps:

6. Establishing the need for change using the principles of change management.
7. Considering Saudi healthcare options.
8. Selecting an appropriate system.
9. Making a plan
10. Maintaining and evaluate the system.

Additionally, the holistic framework was then refined (2nd Version) through the insight of the CoP.

- **Chapter 5 (Questionnaire)**

Primary research was undertaken in the fifth chapter in the form of a questionnaire distributed electronically to numerous individuals, from whom 220 valid responses were acquired. The survey was developed by constructing questions that addressed problems identified in the second chapter. These questions were validated and refined through pilot testing with specialised individuals, and a translation from English to Arabic and back to English was performed to ensure consistency and accuracy of meaning. The questionnaire was administered via social networks, to be completed online over the course of two months or until it was deemed that a sufficient number of responses had been obtained. The reliability of the questionnaire was confirmed through the calculation of Pearson Correlation Coefficients and Cronbach's Alpha of questions in each section of the survey. The data analysis proved that there was overwhelming support for a real-time tracking and monitoring system in Saudi Arabia, and that such a system was also significantly needed. The holistic framework was also further refined to include new sub-factors linked with the four main factors, resulting in a third version of the framework.

- **Chapter 6 (Hospital Workflow Improvement)**

The sixth chapter utilised computer simulation scenarios and proof of concepts trial experiments to demonstrate hospital workflow improvement. Workflow challenges in Saudi Arabia were discussed and related back to the healthcare challenges identified in Chapter 2. Workflow improvements were then taken from the literature and adapted to meet the needs of Saudi healthcare, with tests performed in two parts. The first part, consisted of simulation scenarios that were conducted in the context of hospital healthcare. A Saudi hospital background was used to provide valid representative data for the testing environment used to simulate current practice, and was the same setting all simulated scenarios. Three additional scenarios were modelled with simulation under selected conditions for re-located staff, patients and medical assets, with one variable changed at a time to improve workflow. These relocation scenario simulations indicated substantial workflow improvements that could be obtained in the selected hospital without additional equipment and cost.

In the second part of the chapter, this led to the simulation of a proposed patients' visit scenario that heavily utilised the -Health system. In order to validate the accuracy of the technology, a proof of concepts trial experiment in Staffordshire University Research Centre was undertaken, which proved that ZigBee technology tracking could be used for human movement. A second proof of concepts trial experiment conducted within the Saudi hospital demonstrated a very substantial reduction in search time for staff and medical assets.

- **Chapter 7 (Knowledge Management Transformation)**

In the seventh chapter, knowledge management was introduced and discussed, with focus on the SECI model, which includes Socialisation, Externalisation, Combination and Internalisation. The SECI model was used to demonstrate the methods through which the RTTM system would make possible the transition of knowledge from tacit to explicit in Saudi healthcare.

From this, visualisation was explored in regard to healthcare and knowledge management. A developed system, using both knowledge management and visualisation concepts, was then described and linked with various aspects that the system affected. These aspects include the tracking and monitoring of patients, maternity unit, staff and medical equipment; mobile wayfinding and indoor navigation; a hospital performance dashboard for continual improvement; and hospital staff training and learning tools.

- **Chapter 8 (Validation and Evaluation)**

The eighth chapter began by showing how validation was present in previous chapters, particularly in Chapter 4, when the CoP validated the holistic framework, and in Chapter 6 when the two proof of concepts trial experiments were used to validate the proposed system. Evaluation was then introduced, with the panel of 10 healthcare experts and their diverse backgrounds, which demonstrated through analysis of the results that the system was supportive in the criteria of Ease of Use, Usefulness, Hospital Decision-Making Support, Comprehensiveness, System Functionality and Intention to Use. A series of results was presented and analysed as follows: separated by each criterion, by hospital and by healthcare background. Recommendations for improvement of the RTTM system were provided by participants.

9.3 Contributions to Knowledge

This section provides an overview of the various contributions to knowledge that this research has made, with reference to the aims and objectives given in Chapter 1. This research has achieved the following contributions:

- A holistic framework was developed for tracking and monitoring systems in Saudi healthcare through the integration of the Information System Strategy Triangle (ISST) and Human, Organisation and Technology-fit Factors (HOT-fit) frameworks through the assistance of the established Community of Practice (CoP). The resulting holistic framework consisted of four contexts, which are the human, organisational, technology and business contexts; furthermore, within each of these contexts were multiple factors that outlined key considerations for adopters of the framework. Additionally, an adaptation of the 10 key considerations in the health information technology (HIT) lifecycle (Cresswell et al., 2013) was adopted to assist the change in this research. The framework combined the use of the literature reviews of technologies, Saudi healthcare issues and change management, existing frameworks and Cresswell et al.'s (2013) to create a holistic framework set for refinement.
- A CoP consisting of multidisciplinary Saudi healthcare professionals was formed and assisted in identifying and assessing the factors affecting the development and adoption of RTLS technologies, and in evaluating and validating the developed framework. The CoP consolidated four factors into one and generated ideas for several new factors to be included within the existing contexts. The CoP was also utilised throughout the research for various questions posed by the researcher that could not be found in past studies or had not formerly been considered, and the answers generated by the CoP provided greater foundation for the refined framework.

- A questionnaire survey was conducted to identify current challenges, needs and potential benefits of developing a system for tracking and monitoring patients, staff and medical assets, with analysis of the results providing an additional refinement to the holistic framework that included the addition of two factors.
- Several simulation scenarios for hospital workflow improvements were used, to test various related situations and validate the ability of the integrated RFID/ZigBee system to function as described in the literature.
- Proof of concepts trial experiments were conducted with ZigBee technology, to validate the ability of the RTLS to meet the expectations of this research.
- A system was developed, using knowledge management and visualisation concepts, for real-time tracking and monitoring (RTTM) in Saudi hospitals. This contribution provides an iterative and adaptive process post-implementation that encourages the system to be consistently maintained and improved as the organisation sees fit.

These contributions relate directly to the aims and objectives introduced in Chapter 1. Therefore, it is beneficial to provide a step by step comparison of the objectives and of the methods through which the objectives were achieved, to demonstrate their fulfilment. Table 9.1 shows this comparison and includes a column with the chapter number where the objective was achieved.

Table 9.1 Achievement of the Objectives

No	Objective	Method of Investigation	Chapter
1	To carry out a literature review on challenges and barriers of the healthcare system in Saudi Arabia and worldwide.	Academic papers and reports were reviewed in order to address the challenges of the Saudi and global healthcare systems.	2
2	To carry out a literature review on use of indoor positioning and real-time locating system (RTLS) technologies in tracking and monitoring patients, staff and assets in the healthcare environment.	Academic papers and reports were reviewed in order to identify indoor positioning and real-time locating system (RTLS) technologies and to understand their concepts and benefits.	3
3	To carry out a literature review on the change management implications and workflow operations in the healthcare environment.	Academic papers and reports were reviewed in order to use change management principles to improve hospital workflow.	4
4	To develop a holistic framework for tracking and monitoring systems in Saudi healthcare.	A holistic framework was developed by integrated ISST and HOT-fit frameworks.	4
5	To develop a Community of Practice (CoP) of healthcare professionals in Saudi Arabia to assess factors that affect the development and adoption of tracking and monitoring technologies.	As a qualitative strategy, the CoP was used to identify and assess the factors that affect the development and adoption of tracking and monitoring technologies.	4
6	To conduct a survey in Saudi Arabia to collect related data to assess current challenges and potential benefits of developing a system for tracking and monitoring patients, staff and assets in healthcare.	As a quantitative strategy, a questionnaire was used to identify current challenges and potential benefits of developing a system for tracking and monitoring patients, staff and assets.	5
7	To improve hospital workflow by using simulation concepts.	Simulation scenarios were used to test potential situations to help improve hospital workflows by minimising workflow bottlenecks.	6

8	To conduct proof of concepts trial experiments and to discuss their results.	ZigBee technology was used to ensure that these tracking and monitoring technologies are reliable and significantly improve healthcare processes as discussed in the literature.	6
9	To develop a Smart e-Health holistic system based on the SECI model to support decision makers using knowledge management and visualisation concepts to improve patient and staff workflow and medical equipment utilisation.	A real-time tracking and monitoring (RTTM) system was developed that integrates concepts from knowledge management and visualisation for application in several aspects of the healthcare environment.	7
10	To validate and evaluate the proposed system based on information from a panel of experts from the KSA.	A panel of experts consisting of 10 participants was used to generate useful feedback and to evaluate the system.	8

9.4 Limitations

The many contributions of this research are listed above, and the results outlined many positive outcomes for e-Health in Saudi Arabia. There were some limitations, however, which are identified as follow:

- The perspective of patients was not acquired in the questionnaires, due to the University and the hospital regulations. Patients' feedback might have made possible to better understand user requirements on the patient level.
- The respondents for the questionnaire in Chapter 5 were 84% males, due to the fact they are the majority of labour forces in the KSA (84.4% Males and 14.6% Females) (Saudi General Authority for Statistics, 2018). More female respondents might have allowed a better understanding of differences in responses based on gender. The general consensus favouring the RTLS technology and demonstrating need for it in Saudi healthcare reveals that this limitation may not be relevant.
- It may have been beneficial to simulate more scenarios in Chapter 6 to test other indoor positioning technologies discussed in Chapter 3. These simulation scenarios might have shown the comparative advantage of the integrate RFID/ZigBee system. Time and resource constraints are responsible for this limitation.
- Although, the National Transformation Programme (NTP) outlined in 2016 a five-year plan for revitalisation and innovative measures in the Saudi healthcare system, the many objectives devoted to application across the Ministry of Health (MOH) were beyond the scope of this research.

9.5 Challenges

This research has encountered some challenges and obstacles, the most notable of which are outlined below.

- The broad scope of this research led to challenges related to the complex issues related to the entire healthcare system in Saudi Arabia. The complex and changing structure of the Saudi healthcare system had to be taken into account on every step in this research, especially considering the ever-evolving nature of technology systems and the span of this research being three years.

- The five-year plan outlined in the NTP has led to accelerated changes in Saudi healthcare. This research has adapted to ongoing changes, as well as attempting to meet the growing demands of the citizens of the KSA and of the government. Lack of regulations imposed in the healthcare sector also contributed to difficulties in ensuring the research was completed without bias in responses and kept to schedule.
- Coordination of the Community of Practice utilised in this research was often difficult, as the healthcare professionals were located in the KSA. The researcher was able to meet CoPs in his experimental work during his visits to KSA and the other contact was by using online platforms.
- Gathering data for the questionnaire required more time than expected, and many of the responses were unusable since they were not filled out completely or were from a background unrelated to healthcare.
- Obtaining cooperation of the various parties involved in healthcare, such as administration and IT staff, nurses and physicians, was sometimes difficult as healthcare organisations can be complex and busy environments, in which testing procedures and the gathering of data requires more effort and resources than in most situations.

9.6 Reflections

As stated in the introduction, this work was motivated by the prevalent issues facing my home country of Saudi Arabia and were evident in my own observations as well. The literature gave me the necessary statistics to support my claims and narrow my focus on a technology-based solution, but that focus only led to a specialised set of problems that are natural in the intensive research process. The work conducted during the course of this research encountered several setbacks not explicitly listed within the section on challenges, often due to lengthier-than-expected processes and the initially unclear order of operations. The selection of the RFID/ZigBee system was obviously of great importance to this research, for example, but required more time and review of the literature than expected. It ultimately proved fruitful, however, as shown by the sections on its validation and evaluation. Establishment of the CoP and its continued discussions on the ongoing research was more difficult to coordinate than anticipated, but it fulfilled its purpose and validated the literature that had instigated it. The results from the questionnaire were more positive than expected and provided me with optimism prior to the simulations and experiments conducted.

I was very satisfied with the results of the project as I believe it contributed in many ways to research on Saudi healthcare, and I hope it can be useful to healthcare organisations as originally intended. The contributions span the framework, the CoP, the survey, the simulations and experiments and the RTTM system, and all of these have the potential to make future impacts on research and healthcare organisations. The improvements to be made on the holistic framework developed and refined throughout the research appear to be minimal in the short run, as indicated by the panel of experts, and since it is an adaptive framework I believe it will maintain its strength until technology reaches a more advanced phase. The results in general were strong, and were supported by the CoP, the survey respondents and the panel of experts. The recommendations made by the panel of experts were beyond the scope of this research but could be part of future studies, which is the topic of the next and final section.

9.7 Future Work

This research has led to several insights on ideas for future work relating to real-time tracking and monitoring systems in Saudi Arabia. These include:

- Using the ZigBee technology feature of monitoring environmental data (temperature, light and humidity) for a variety of applications, to enable many functions such as the transfer of various medical fluids, e.g. blood bags when facilitating transfusions. Research on this area of study would need to evaluate the accuracy of ZigBee technology with this feature, and to investigate more uses to generate greater applicability.
- Building a Smart network of hospitals within a single healthcare organisation, which would utilise all the data generated by the various RTTM systems implemented at each facility. As these systems may be different, due to the different needs of each hospital, the variations in the results can be observed for better implementation in other hospitals within the organisation. Additionally, the Smart network can be used to enhance interconnectedness of the hospital’s staff, the communication and collaboration of physicians, and the management of medical assets as needed by each hospital. Research

on this development would build on this research and would require analysis of healthcare organisations with multiple hospitals or facilities.

- Meeting the demands outlined by the MOH in its five-year plan with the NTP, by turning to the development of a network between all hospitals in Saudi Arabia under the MOH, to provide benefits listed in the previous point as well as to unify the country in its national healthcare objectives.
- Improving the design of the hospital performance dashboard through the deeper understanding of recurring problems, especially post-implementation of the RTTM system.
- Assessing the suitability of the holistic framework developed in this research, once other functional tracking and monitoring technologies come to market.
- Developing a 'Command Centre' that adopts the concept of the hospital performance dashboard developed in this research and builds on it to form a system by which large healthcare organisations, emergency agencies and MoH activities could be visualised through their RTTM system and the knowledge generated by it, for continual improvements and better management of staff, patients and medical equipment.

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Appendix A1

Submit completed forms to K266, Octagon Bdg (Stafford students) or B161, Brindley Bdg (Stoke students)

STAFFORDSHIRE UNIVERSITY
FAST-TRACK ETHICAL APPROVAL FORM (STUDENTS)

Tick one box: ☐ TAUGHT POSTGRADUATE project ☐ UNDERGRADUATE project ☑ PhD/MPhil project
☐ TAUGHT POSTGRADUATE MODULE assignment
☐ TAUGHT UNDERGRADUATE MODULE assignment
✓ Full-Time Study ☐ Part-Time Study ☐
☐ Other project (Please state ……………………………………………………………………………)

Title of project: **Smart e-Health Framework for Tracking and Monitoring Patients and Assets to Support Decision Makers in Saudi Arabia Healthcare**

Title of Award: **PhD**……………………………………………………………………………………

Name of student researcher: **Awad ALYAMI**………………………………………………………

Student Number: **12033791**……………………………………………………………………………

Name of supervisor: **Prof. Anthony S. Atkins** ……………………………………………

Student Researchers- please note that certain professional organisations have ethical guidelines that you may need to consult when completing this form.

You will also need to undertake a risk assessment for the research project in consultation with your supervisor. A sample risk assessment form is available at Be ethical Completed risk assessment forms should be submitted to your academic supervisor for consideration and approval.

Supervisors/Module Tutors - please seek guidance from the Chair of your Faculty Ethics Committee if you are uncertain about any ethical issue arising from this application.

		YES	NO	N/A
1	Will you describe the main procedures to participants in advance, so that they are informed about what to expect?	✓		
2	Will you tell participants that their participation is voluntary?	✓		
3	Will you obtain written consent for participation?			✓
4	If the research is observational, will you ask participants for their consent to being observed?			✓
5	Will you tell participants that they may withdraw from the research at any time and for any reason?	✓		
6	With questionnaires and interviews will you give participants the option of omitting questions they do not want to answer?	✓		
7	Will you tell participants that their data will be treated with full confidentiality and that, if published, it will not be identifiable as theirs?	✓		
8	Will you give participants the opportunity to be debriefed i.e. to find out more about the study and its results?	✓		

If you have ticked **No** to any of Q1-8 you should complete the full Ethics Approval Form.

		YES	NO	N/A
9	Will your project deliberately mislead participants in any way?		✓	
10	Is there any realistic risk of any participants experiencing either physical or psychological distress or discomfort?		✓	
11	Is the nature of the research such that contentious or sensitive issues might be involved?		✓	

Submit completed forms to K266, Octagon Bdg (Stafford students) or B161, Brindley Bdg (Stoke students)

If you have ticked **Yes** to 9, 10 or 11 you should complete the full Ethics Approval Form. In relation to question 10 this should include details of what you will tell participants to do if they should experience any problems (e.g. who they can contact for help).

			YES	NO	N/A
12	Does your project involve work with animals?			✓	
13	Do participants fall into any of the following special groups? **Note that you may also need to obtain satisfactory CRB clearance (or equivalent for overseas students)**	Children (under 18 years of age)		✓	
		People with communication or learning difficulties		✓	
		Patients		✓	
		People in custody		✓	
		People who could be regarded as vulnerable		✓	
		People engaged in illegal activities (eg drug taking)		✓	
14	Does the project involve external funding or external collaboration where the funding body or external collaborative partner requires the University to provide evidence that the project had been subject to ethical scrutiny?			✓	

If you have ticked **Yes** to 12, 13 or 14 you should complete the full Ethics Approval Form. There is an obligation on student and supervisor to bring to the attention of the Faculty Ethics Committee any issues with ethical implications not clearly covered by the above checklist.

If you have ticked **Yes** to 13 and your participants are **patients** you must follow the Guidelines for Ethical Approval of NHS Projects.

STUDENT RESEARCHER
Provide in the boxes below (plus any other appended details) information required in support of your application. THEN SIGN THE FORM.

Please Tick Boxes

I consider that this project has no significant ethical implications requiring a full ethics submission to the Faculty Ethics Committee.	✓
Give a brief description of participants and procedure (methods, tests used etc) in up to 150 words. This project will be carried out in Saudi Arabia. The aim of this research is to propose and develop a novel smart e-Health framework for assessing the tracking and monitoring patients and assets for healthcare decision support in Saudi Arabia with attention of using RFID and ZigBee technologies. The proposed framework will be at a strategic-level and will be developed by using knowledge management concepts in relation to the visualisation to identify an appropriate managerial decision support framework in order to identify patients, medical staff and medical equipment locations and utilisation to improve efficiency and the decision support systems and to be appropriate to the needs of Saudi Arabia.	
I also confirm that: ii) All key documents e.g. consent form, information sheet, questionnaire/interview are appended to this application.	

Submit completed forms to K266, Octagon Bdg (Stafford students) or B161, Brindley Bdg (Stoke students)

Or ii) Any key documents e.g. consent form, information sheet, questionnaire/interview schedules which need to be finalised following initial investigations will be submitted for approval by the project supervisor/module leader before they are used in primary data collection.	

Signed... ... ... Print Name... Awad ... ... Date... 9th June 2015
(Student Researcher)
The completed form (and any attachments) should be submitted for consideration by your Supervisor/Module Tutor

SUPERVISOR
PLEASE CONFIRM THE FOLLOWING: **Please Tick Box**

I consider that this project has no significant ethical implications requiring a full ethics submission to the Faculty Ethics Committee	✓
i) I have checked and approved the key documents required for this proposal (e.g. consent form, information sheet, questionnaire, interview schedule) Or	✓
ii) I have checked and approved draft documents required for this proposal which provide a basis for the preliminary investigations which will inform the main research study. I have informed the student researcher that finalised and additional documents (e.g. consent form, information sheet, questionnaire, interview schedule) must be submitted for approval by me before they are used for primary data collection.	

SUPERVISOR AND SECOND ACADEMIC SIGNATORY

STATEMENT OF ETHICAL APPROVAL (please delete as appropriate)

1) THIS PROJECT HAS BEEN CONSIDERED USING AGREED UNIVERSITY PROCEDURES AND IS NOW APPROVED

2) THIS PROJECT HAS BEEN APPROVED IN PRINCIPLE AS INVOLVING NO SIGNIFICANT ETHICAL IMPLICATIONS, BUT FINAL APPROVAL FOR DATA COLLECTION IS SUBJECT TO THE SUBMISSION OF KEY DOCUMENTS FOR APPROVAL BY SUPERVISOR (see Appendix A)

Signed... A.S. Atkins ... ... Print Name... Anthony S. Atkins ... Date... 9/6/2015
(Supervisor/Module Tutor)

APPENDIX A
AUTHORISATION FOR USE OF KEY DOCUMENTS

Completion of Appendix A is required when for good reasons key documents are not available when a fast track application is approved by the supervisor/module leader and second academic signatory.

I have now checked and approved all the key documents associated with this proposal e.g. consent form, information sheet, questionnaire, interview schedule

Signed... RC Campion ... ... Print Name... RUSSELL CAMPION... Date... 9/6/15
(Supervisor/Module Tutor)

Submit completed forms to K266, Octagon Bdg (Stafford students) or B161, Brindley Bdg (Stoke students)

NB A departure from the protocol set out in this application may invalidate the basis for a fast track approval decision. Any proposal to depart from the protocol described in this fast track application should be discussed with the project supervisor as soon as possible. If it is intended to go ahead with research based on a revised protocol a further ethical approval proposal must be submitted. No research based on a revised protocol should proceed unless and until the revised protocol is approved.

Appendix A2

Kingdom of Saudi Arabia Ministry of Health King Fahad Medical City (162)	المملكة العربية السعودية وزارة الصحة مدينة الملك فهد الطبية (١٦٢)

وزارة الصحة
مدينة الملك فهد الطبية
King Fahad Medical City

IRB Registration Number with KACST, KSA:	H-01-R-012
IRB Registration Number with OHRP/NIH, USA:	IRB00010471
Approval Number Federal Wide Assurance NIH, USA:	FWA00018774

April 13, 2016
IRB Log Number: 16-135E
Department: External
Category of Approval: EXEMPT

Dear Awad AlRasheed,

I am pleased to inform you that your submission dated April 4, 2016 for the study titled '**Tracking and Monitoring Patients and Assets in Saudi Arabia Healthcare Environment**' was reviewed and was approved. Please note that this approval is from the research ethics perspective only. You will still need to get permission from the head of department or unit in KFMC or an external institution to commence data collection.

We wish you well as you proceed with the study and request you to keep the IRB informed of the progress on a regular basis, using the IRB log number shown above.

Please be advised that regulations require that you submit a progress report on your research every 6 months. You are also required to submit any manuscript resulting from this research for approval by IRB before submission to journals for publication.

As a researcher you are required to have current and valid certification on protection human research subjects that can be obtained by taking a short online course at the US NIH site or the Saudi NCBE site followed by a multiple choice test. Please submit your current and valid certificate for our records. Failure to submit this certificate shall a reason for suspension of your research project.

If you have any further questions feel free to contact me.

Sincerely yours,

KFMC
Approved
13 APR 2016
IRB

Prof. Omar H. Kasule
Chairman Institutional Review Board--IRB.
King Fahad Medical City, Riyadh, KSA.
Tel: + 966 1 288 9999 Ext. 26913
E-mail: okasule@kfmc.med.sa

Appendix A3

Regarding Mr. Awad's research

Ahmed Aboabat <Aaboabat@kfmc.med.sa>

Mon 5/25/2015 3:39 PM

To: ATKINS Anthony <A.S.Atkins@staffs.ac.uk>;

Cc: ALYAMI Awad <a033791c@student.staffs.ac.uk>; Mr. AWAD <awad.vip@gmail.com>; Awad A. AlRasheed <aalrasheed@kfmc.med.sa>;

Professor Tony Atkins
Faculty of Computing, Engineering and Sciences
Staffordshire University.

Dear Professor Atkins
I am Dr. Ahmed Aboabat, the Associate Executive Director of Patient Affairs at King Fahad Medical City (KFMC), I am pleased to write this email to you supporting Mr. Awad AlRasheed research in Health Informatics area. I knew Mr. Awad for many years and I knew him much closer when I take over the charges of patient affairs services as he was the Director of Outpatient Services Administration for many years. He was involved in the business of health informatics during his work at KFMC which is one of the largest healthcare organization at Saudi Arabia. His contribution extended to the national level as KFMC is a real model in health informatics in the country so this gave him the chance to be aware about the Saudi healthcare environment.

I am confident that his research will have a positive impact on the business of King Fahad Medical City.

please let me know if i can be of any further assistance.

Best regards,
Ahmed M. AboAbat, BScPT, MHA, PhD
Rehabilitation Consultant

Founder and Former Director, Rehabilitation Hospital
Associate Executive Director of Patient Affairs
Advisor to the deputy Minister of Health
Chairperson, Clinical Services Career Planning and Credentilaing Committee
----
King Fahad Medical City
P O Box 69762, Riyadh 11557
Phone # +966 - 1 - 1288 9999, ext. 9891, 17058
Fax # +966 - 1 - 12889000, ext. 7061
aaaboabat@kfmc.med.sa
@aboabat

Appendix A4

Mon 18/05/2015 14:10

Mohammed F. Alsubaie <mfalsubaie@pnu.edu.sa>

Mr. Awad's research

To ATKINS Anthony

Cc ALYAMI Awad

Action Items

Dear Professor Tony Atkins,

Staffordshire University

As Automation Manager of King Abdullah bin Abdulaziz University Hospital, I am pleased to write this letter in support of Mr. Awad's research.

Recently, Mr. Awad and I had a comprehensive discussion about the challenges and issues that we are facing currently and how can we work together to overcome them.

We believe his research is important, feasible, and consistent with the goals of King Abdullah bin Abdulaziz University Hospital.

I am hopeful that his research and projects will be a success.

Regards,

Mohammed Alsubaie

Automation Manager

Informatics & Technology Executive Department

King Abdullah bin Abdulaziz University Hospital

✉: mfalsubaie@pnu.edu.sa | ☎: +966 11 82 46215

Appendix A5

Tracking and Monitoring Patients and Assets

STAFFORDSHIRE UNIVERSITY

Research Title
Smart e-Health Framework for Tracking and Monitoring Patients and Assets to Support Decision Makers in Saudi Arabia Healthcare

Researcher Contact Information	
Name	Awad Ali AlYami
Phone	00966 544150111- 0044 7762585405
E-mail	A033791C@student.staffs.ac.uk

Description
This study is being undertaken as part of the PhD research study for Awad Ali AlYami. The Ministry of Higher Education in Saudi Arabia sponsors this research. The sponsor of this research will not have access to the obtained data. The purpose of this research is to develop a smart e-health framework for tracking and monitoring patients and assets to support decision makers in Saudi Arabia healthcare. As a researcher, I request your help by participating to the questionnaire of this study. This study will benefit the healthcare sector in Saudi Arabia, as it will provide required support to the decision makers in Saudi Arabia healthcare. Please note that:

- DO NOT participate in this questionnaire if you are vulnerable to coercion or undue influence (e.g., unable to consent, less than 18 years, prisoner, etc.).
- All answers will be treated in confidence and names of participants are not required.
- You can stop at any time during the questionnaire.
- While your cooperation in answering every question will help us understand important questions with regards to e-Health acceptance, you are not obligated to answer every question.
- Your participation in this project is voluntary.
- If you agree to participate, you can withdraw from participation at any time without any consequences (incomplete and dropped questionnaires will be counts).
- There are no direct benefits to you for participating in this research.
- There are no risks associated with participation.
- By your return of the completed questionnaire, you consent to participate in this study.
- This questionnaire is available in two languages (Arabic and English).

Section 1: Profile Questions

In this section of the study you will be asked to provide demographic information about yourself. Please choose one answer for each question.

Please specify your gender:

- Male
- Female

Please specify your computer skills:

- Low (don’t use computer or other electronic devices)
- Medium (I use basic computer applications i.e., MS-Office, e-mail or web browsing)
- High (I deal with hardware maintenance and use specialists software such as databases and networking programs)

Please specify your age:

- 18 -30
- 31 - 40
- 41 - 50
- 51 - 60
- Over 60

Please specify your education level:

- High school
- Bachelor
- Master
- Doctorate
- Others; specify: …………………..

Please specify your role in the healthcare sector:

- Medics/healthcare (doctor –nurse – pharmacist)
- Healthcare Technician
- Ancillary Staff
- Administrative Staff
- IT specialist
- Other; specify: …………………..

Section 2: Yes / No Questions

PLEASE REFER TO EACH QUESTION AND CHOOSE WHAT YOU THINK IS THE BEST ANSWER. PLEASE THINK ABOUT EVERY QUESTION BEFORE CHOOSING THE ANSWER.

1- Can you track and locate patients and assets in your hospital.
   - Yes
   - No
   If Yes, Please specify…

2- Is there a system in place to measure staff productivity in your hospital?
   - Yes
   - No
   If Yes, Please specify…

3- Is your current Hospital system able to verify an individual's status regarding access to area like maternity, ICU and so on?
   - Yes
   - No
   If Yes, Please specify…

4- Do you have a difficult in misplacing or losing medical assets and mobile equipment's in your hospital very often?
   - Yes
   - No
   If Yes, Please specify time…

5- Are you satisfied with the current practice of tracking assets at your hospital?
   - Yes
   - No
   If No, Please indicate improvements suggestions:
   ……………………………………………………………….

6- Do you feel there is a need for tracking and locating patients and assets in your hospital to assist and improving efficiency?
   - Yes
   - No

Section 3: Multiple Choice Questions

PLEASE REFER TO EACH QUESTION AND CHOOSE WHAT YOU THINK IS THE BEST ANSWER. PLEASE THINK ABOUT EVERY QUESTION BEFORE CHOOSING THE ANSWER.

1- On average, how long patients have to wait until seen by a doctor in your hospital?

- Less than 10 minutes
- 10 – 30 minutes
- 30 – 60 minutes
- Over 60 minutes, please specify time:

2- How often are emergency rooms in short supply or no-supply of needed medical equipment?

- Very often
- Often
- Somewhat often
- Not often
- Never

3- If tracking and monitoring system have been implemented in your hospital, patients can be tracked as they move about the facility, enabling them to be quickly located for scheduled treatments or procedures.

- Strongly agree
- Moderately agree
- Neutral

- Moderately disagree
- Strongly disagree
- I don't know

4- A tracking system will enables better protection of vulnerable patients by sounding an alarm when patients leave designated areas.

- Strongly agree
- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

5- Patient tracking system can help in preventing and eliminating human and medical error such as patient misidentification.

- Strongly agree
- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

6- ID tags for patient relatives and hospital visitors will increase the accuracy of verifying the individual’s status and areas of access like maternity, ICU and etc.

- Strongly agree

- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

7- A tracking system will help the hospital to detect who enters or leaves a controlled area and notes their ID, status and time of access.

- Strongly agree
- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

8- Locating life-saving and critical care equipment quickly, will improve patient care and staff productivity.

- Strongly agree
- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree

- I don't know

9- Updating responsible staff by a tracking system when beds, wheelchairs and other equipment are unavailable / on shortage will allow for faster patient/room turnover and improve hospital overall utilization.

- Strongly agree
- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

10- Tracking assets system will result in tighter asset control and lower replacement costs.

- Strongly agree
- Moderately agree
- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

11- A tracking and location patients and assets system in Healthcare institutions in Saudi Arabia will help in performance and efficiency.

- Strongly agree
- Moderately agree

- Neutral
- Moderately disagree
- Strongly disagree
- I don't know

End of questionnaire.

Thank you for your participation.

If you have any questions about the questions or this study, please find the contact information here below:

Awad Al Yami,

PhD Researcher

Staffordshire University

A033791C@student.staffs.ac.uk

Professor Anthony Atkins

Staffordshire University

a.s.atkins@staffs.ac.uk

Dr. Russell Campion

Staffordshire University

r.j.campion@staffs.ac.uk